R. Cozeret – J. Chambarel – S. Phoudiah – D. Corbin – S. Pignet

Improvement on 900 MWe NPPs in the occasion of the 4th 10-year Periodic Safety Review on Severe Accidents

Outlines

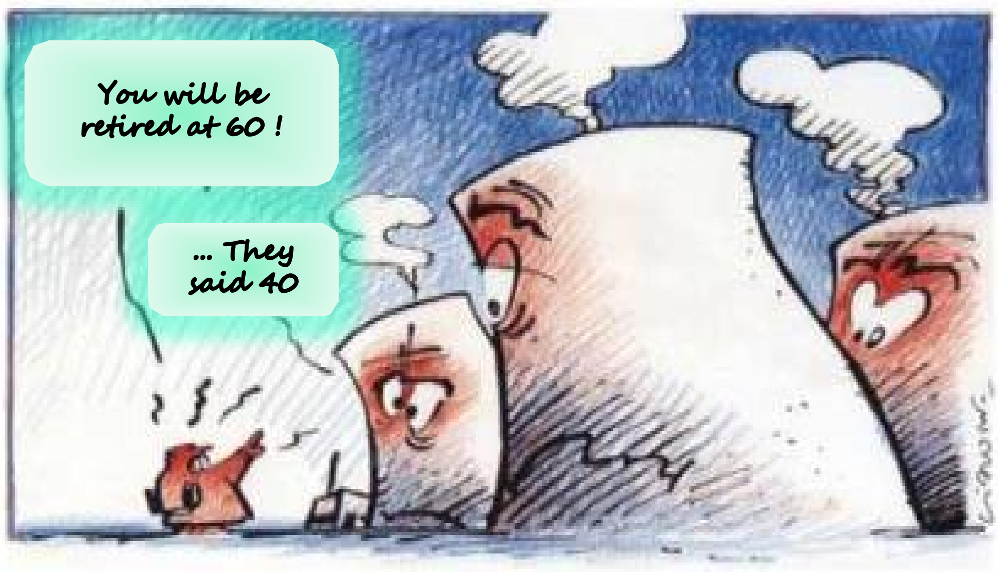
- Introduction
- Assessment of measures aimed to allow corium stabilization without concrete basemat melt-through
- Assessment of measures aimed to remove heat from the containment without venting
- Assessment of iodine chemistry in the containment
- Conclusions

Introduction

- French regulatory framework: no lifetime limit but PSRs every 10 years.

- Concerned 900MWe (34 reactors) started operation from 1978 to 1987 whereas 1300MWe and 1450MWe are more recent.

- After FDNP situations, EDF started its Plant Lifetime Extension program (PLE) with the 900 MWe 4th periodic safety review. FDNP lessons have to accounted.



- For this LTO program, the ASN (regulator) supported by IRSN (TSO) requested EDF for improvements to get closer to Gen. III design (as EPR) safety levels especially for severe accident mitigation.

- For low pressure core melt accident situations: only limited protective measures in area and time needed to protect the population.

Introduction

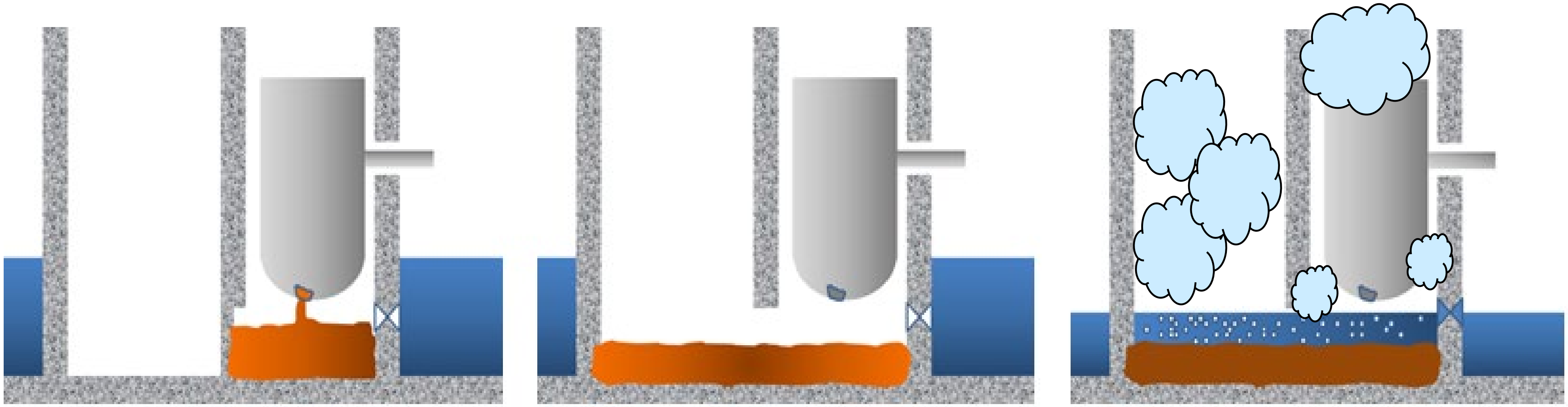
- EDF reviewed its initial LPE program after FDNP accidents and included two important upgrades on severe accident management and mitigation on operating NPPs to fulfill specific ASN requests :
  - A strategy to allow corium stabilization before concrete basemat melt-through
  - A strategy to remove residual heat out of containment without venting

✓ *The analyzes by IRSN of these upgrades have been supported by a large simulation program based on ASTEC V2.1.*

✓ *IRSN also considered iodine source term to investigate the gap with Gen III reactors in terms of objectives for the limitation of the population protection measures.*

✓ *The conclusions of IRSN have been presented to the ASN standing group of experts in March 2019.*

Measures for corium stabilization



1. Preventive filling of the containment sumps by water once the SA criteria has been reached.

2. Dry spreading of the corium on the reactor basemat and an extended area after ablation of a fusible concrete gate.

3. Passive top-reflooding of corium through several flooding gates.

4. Ultimate heat sink lined by the EDF nuclear rapid response force (EDF rescue team) (FARN) 24h at the latest after accident beginning.

Main issues addressed by IRSN

- The vessel cavity and the adjacent area need to remain dry before vessel rupture to avoid FCI and to allow a complete spreading of the corium before the reflooding.

- The timing of the reflooding needs to be appropriate (to fast limits spreading and increases FCI risk and too slow means a large amount of concrete is ablated).

- The water height in the sump at flooding actuation needs to be sufficient regarding the reflooding flowrate and the height of water flooding the corium.

- The depth of undamaged basemat needs to remains sufficient to prevent a containment failure.

This presentation

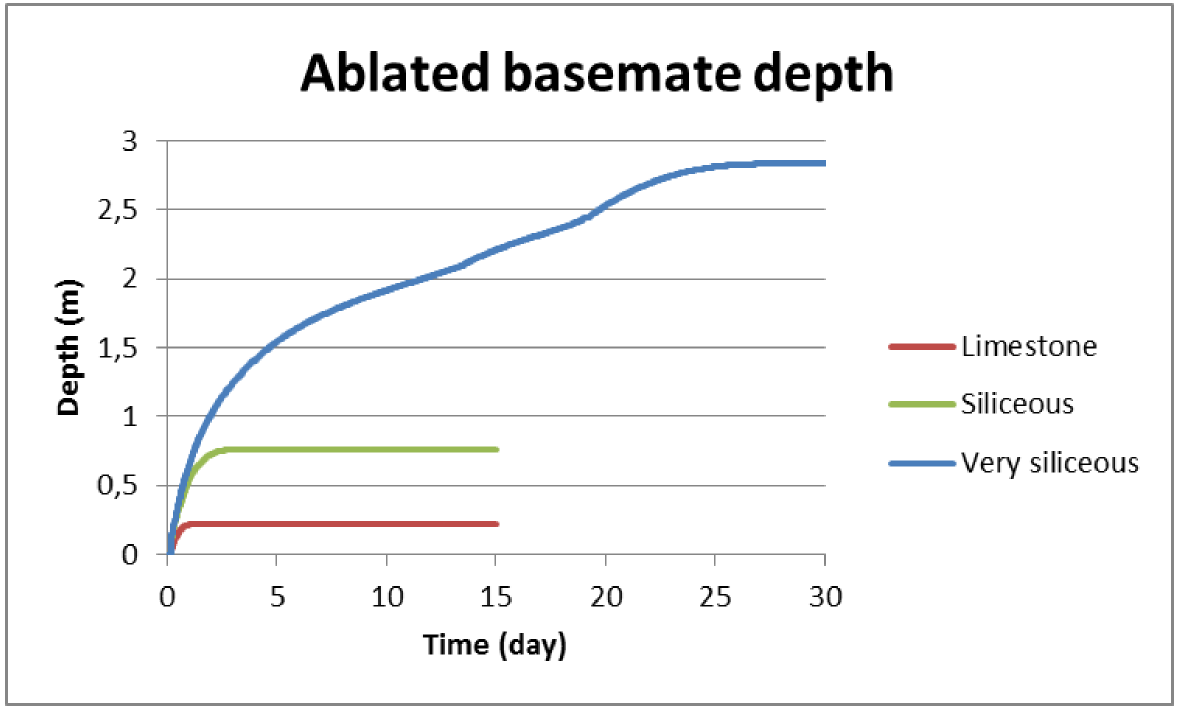
- The top cooling efficiency needs to be sufficient to allow corium stabilization.

Qualitative conclusion of supporting R&D on top cooling

- The earlier the top cooling will be the more efficient cooling mechanisms will be.
- Ablation rates and top cooling efficiency strongly depends on the concrete characteristics:
  - For limestone concrete, heat exchanges with water are efficient.
  - For siliceous concrete, the cooling mechanism efficiency remains uncertain and will significantly be lower down by the incorporation in the melt of concrete decomposition compounds.

IRSN evaluation of ablated basemat depth

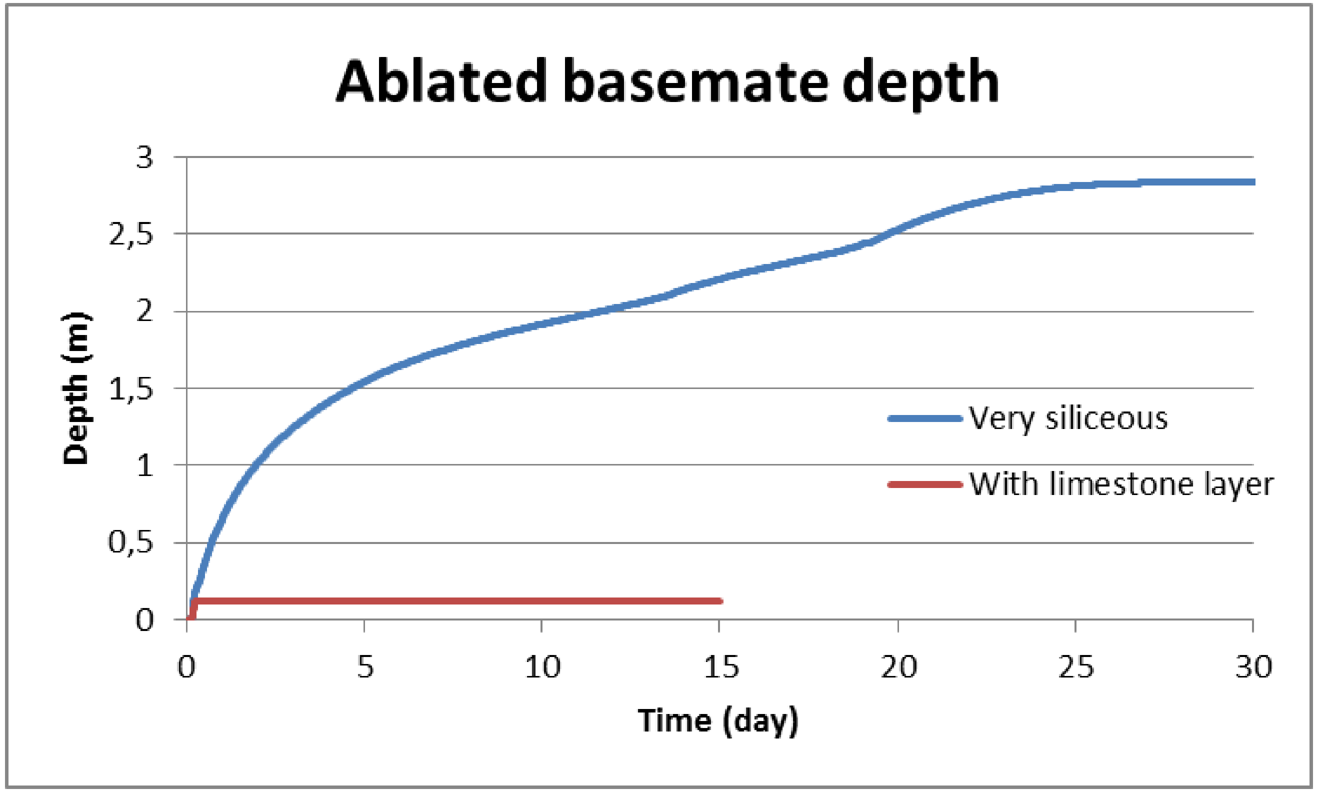
- For LCS and mildly siliceous concrete, the ablated basemat depth is small (<1m).
  - ☺ *Globally confident that the measures are sufficient to prevent basemat melt-through.*
- For very siliceous concrete, much more significant concrete ablation (~3m).
  - ☹ *Highlight uncertainties on MCCI including water ingression efficiency.*



Improvement with additional layer

- IRSN considers that uncertainties remains for siliceous concrete ablation and top cooling.

- In addition, ASTEC simulations considering an additional layer of highly limestone concrete show ablated concrete depth reduction to about 20 cm (instead of 3m).



→ *IRSN recommends to thicken the basemat with a 40 cm layer of limestone concrete.*

Decay heat removal without venting the containment

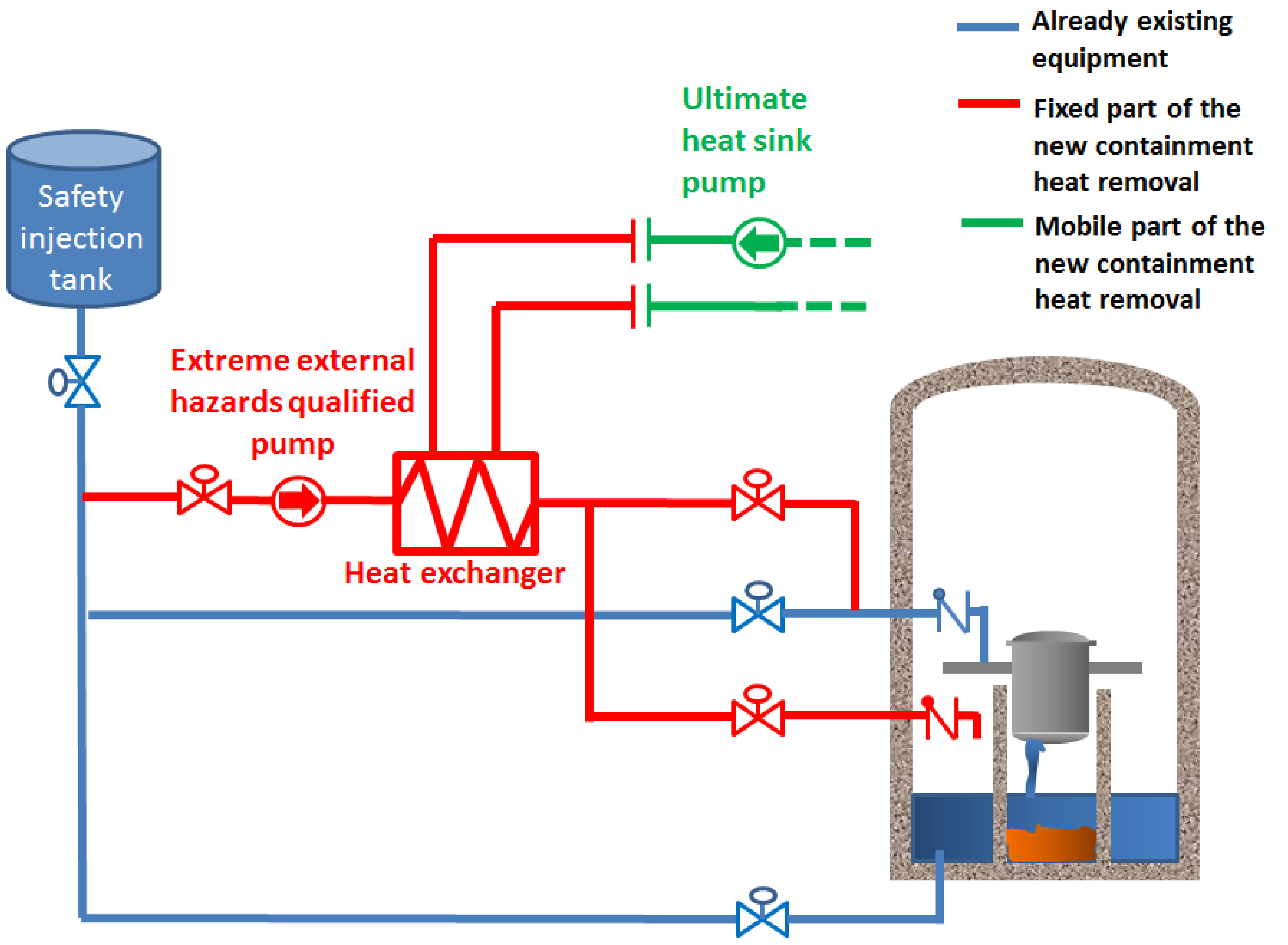
A PUMP qualified to extreme external hazards and SA

An INJECTION LINE to the primary coolant circuit and another feeding the sumps

A SUCTION LINE connected to the safety injection tank and another pumping in the sumps

A HEAT EXCHANGER

An Ultimate HEAT SINK to be lined by the EDF rescue team



Main issues addressed by IRSN

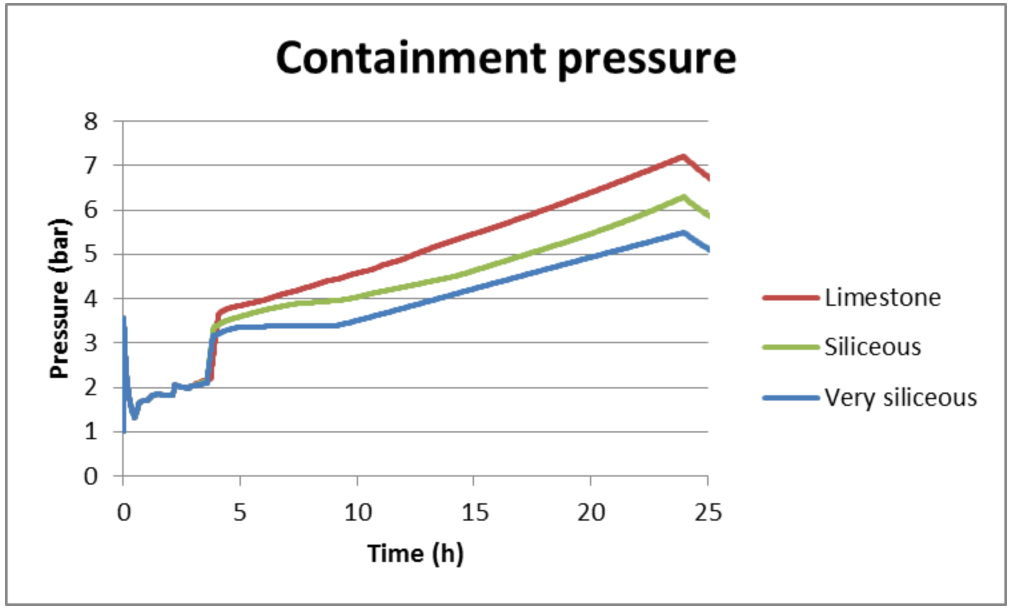
- This new heat removal system operates in to steps:
  - direct injection : the pump preventively fills the sump of the reactor building with water coming from the safety injection tank before the vessel failure, allowing to flood the corium when passive flooding system actuates
  - recirculation: once the ultimate heat sink has been lined by the FARN, within 24 hours, the recirculation is activated, allowing to remove decay heat thanks to the heat exchanger
- Two criteria have to be respected:
  - the containment pressure needs to remain under 5 bar
  - the sump water temperature needs to remain under 140°C

Grace period evaluation with ASTEC V2.1

- Simulations to evaluate the grace period during which the two criteria (5 bar, 140°C) are fulfilled before the ultimate heat sink is settled

- Simulations with ASTEC V2.1
  - scenarios : LOCA 4" and 12"
  - EASu activation at 24 h
  - 3 types of basemat concrete
  - with passive flooding

☹ *Situations exist for which the grace period is significantly shorter than 24h.*



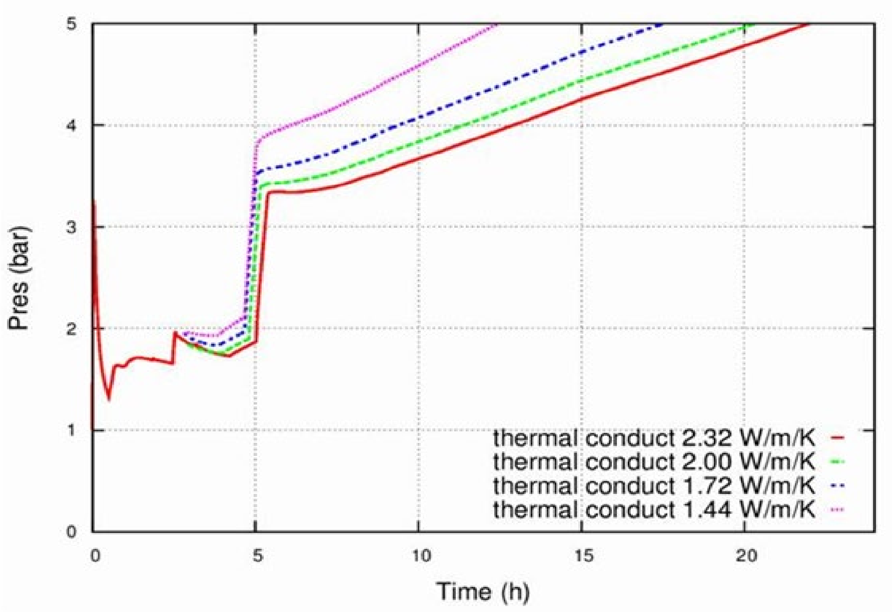
Concrete type	Limestone		Siliceous	Very siliceous
Scenario	LOCA 4"	LOCA 12"	LOCA 12"	LOCA 12"
5 bar	14h00 min	12h30 min	17h	20h30 min
140 °C	22h30 min	20h30 min	22h30 min	> 24h

Sensitive parameters

- The type of concrete ablated by the corium : the more the concrete contains limestone, the more efficient the heat transfer is, leading to faster pressurization.
- The initial mass and temperature of the corium : core degradation simulation are uncertain and strongly sensitive to small variations of the accident sequence.

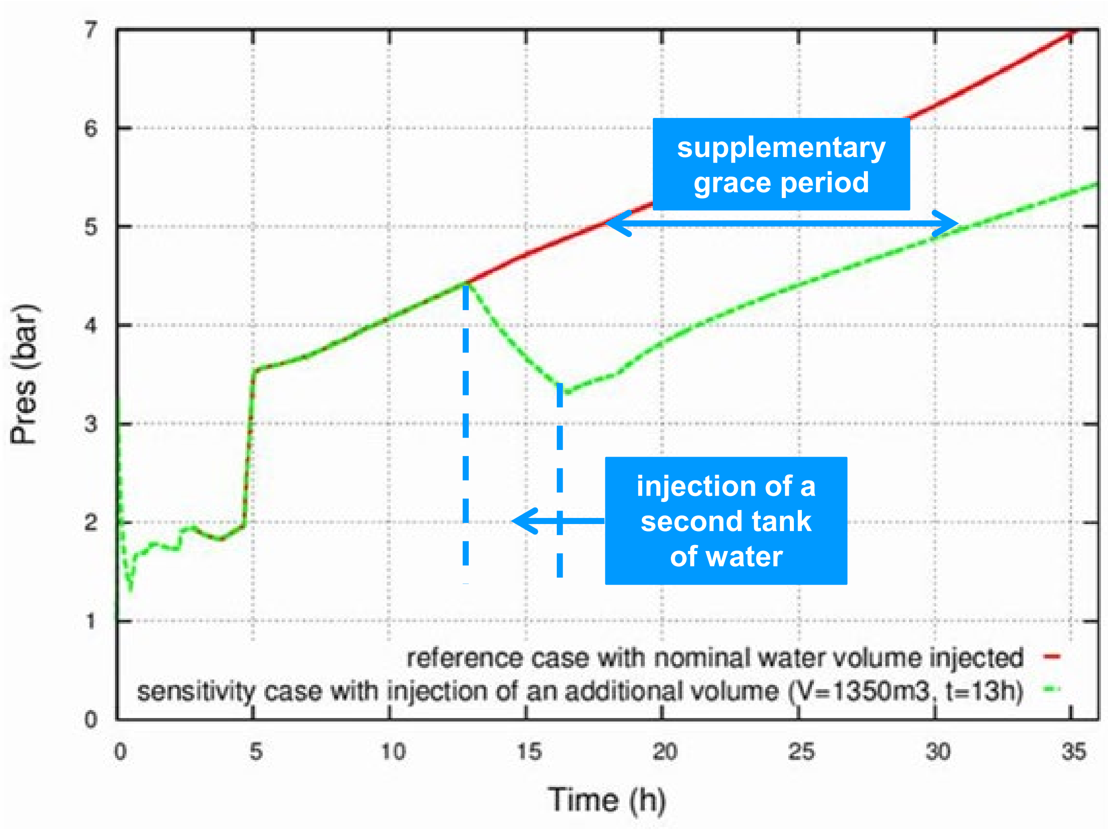
  → conservative assumptions fore the amount, temperature and composition of the corium

- The containment wall concrete thermal conductivity: difficult to evaluate with accuracy for a reactor building. Very sensitive parameter in terms of kinetics of pressurization.



Injection of a second tank of water

The injection of a second tank of water in the containment could increase the delay before containment over-pressurization.



☺ *IRSN recommends preventively filling and flowing ASAP a second tank of water in the containment.*

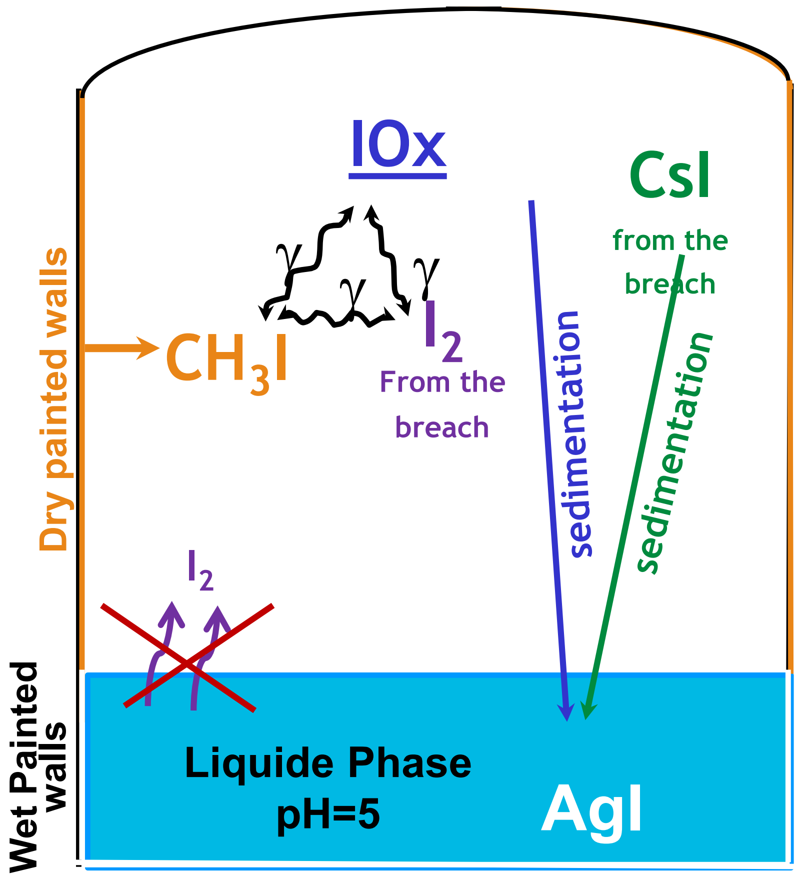
Iodine chemistry in the containment

- Iodine is a very sensitive fission product on doses for population.

  → specific focus on it in the framework of LPE

- Being highly reactive, iodine chemistry is very complex.

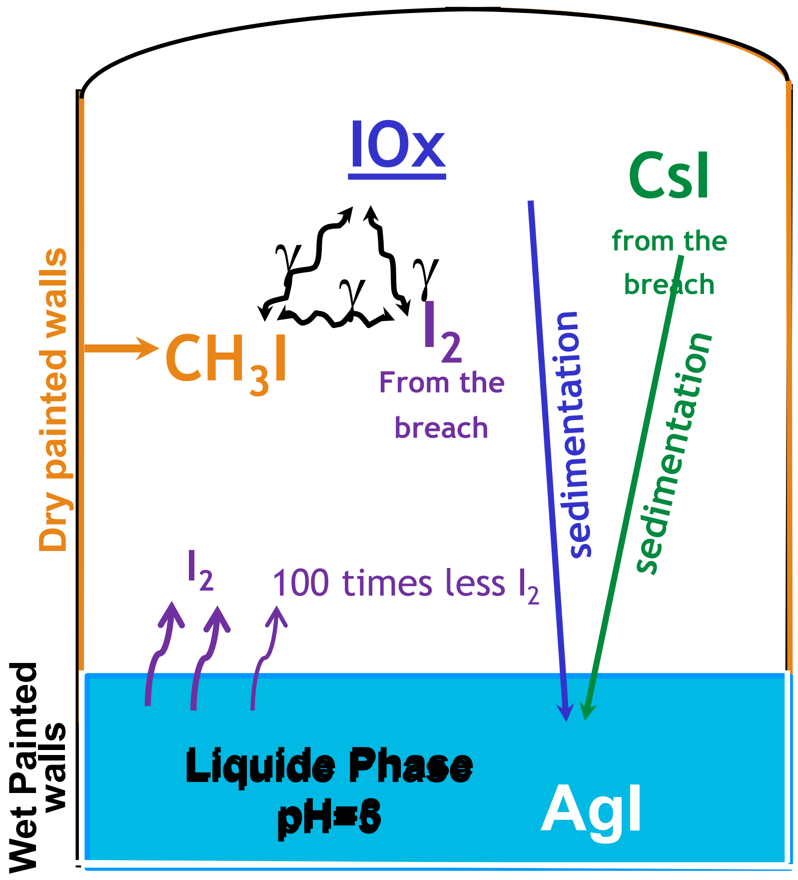
- Due to the presence of silver particle produced by the vaporization of SIC control rods and then settled in the sump, the iodine source term was expected to be lower than for others plants (formation of soluble AgI compounds).



- But recent analyses of R&D programs led to limit the efficiency of iodine trapping by silver (external surface of particle only).

Iodine chemistry in the containment

- I_2 emission from the sump is also very sensitive to sump acidity:
  - Massive emission for acid sump (pH=5) stored in IOx form
  - Approximatively 100 times less for basic sump (pH=8)
  - Basification of sump was the solution retained for B4C control rods plants



→ *IRSN recommends to insure also for 900MWe plants a basic sump in severe accident conditions.*

Conclusions

- Main modifications of existing French Operating Nuclear Power Plant concerning Life Time Operation Extension are aimed to bring existing Gen. II fleet to safety levels of Gen. III as concerns SA mitigation.
- The strategy proposed by EDF aims to stabilizing the corium out of the vessel while preventing containment by-pass and brings significant safety improvements.
- ASTEC V2.1 safety studies were performed by IRSN to inform regulator notably concerning basemat melt-through, containment over-pressurization risks, and iodine releases.
- Theses studies leads IRSN to recommend:
  - Additional limestone concrete layer for more siliceous basemat so preventing melt-through
  - A second water tank injection before rescue team intervention to prevent containment over-pressurization
  - A basic sump in severe accident conditions to reduce gaseous iodine inventory in the containment