IRSN
INSTITUT
DE RADIOPROTECTION
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Faire avancer la sûreté nucléaire

Strategy for the corium stabilisation in case of a severe accident for the French PWRs

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Shanghai, China
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Outline

1. Choice of a strategy for corium stabilization

2. The R&D in support of that strategy

Context

In 2009, EDF started its project to extend the operating life of its Gen II PWRs beyond 40 years. It implied :

- a specific program for ageing management,
- a safety reassessment in light of the requirements applicable to new reactors (EPR) and the state of the art of nuclear technologies

-- > Prevention of basemat melt-through in case of a severe accident was one issue considered in that framework.

Then, post-Fukushima actions were launched in France and the importance of that issue was confirmed.

French Nuclear Safety Authority order
(ASN n°2014-DC-0394 à 412 from January 21st, 2014) :

« … the setting up (by EDF) of a system … to prevent basemat melt-through by the corium … ».

2 strategies have been studied by EDF

1. The reactor cavity is filled with water : this water can help keeping the vessel integrity (in-vessel melt retention). In case of vessel failure, the corium falls in the water of the reactor cavity.

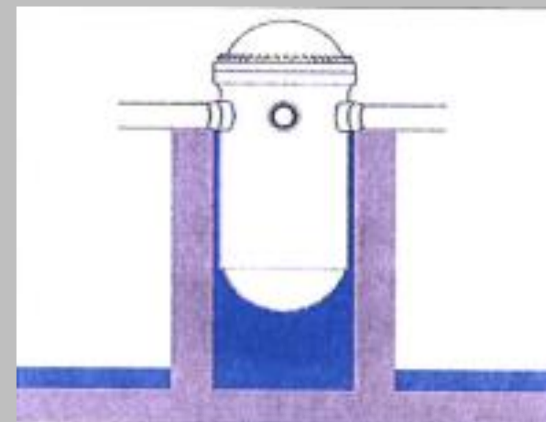
2. The reactor cavity remains dry until the vessel failure and water is injected into the reactor cavity after corium spreading.

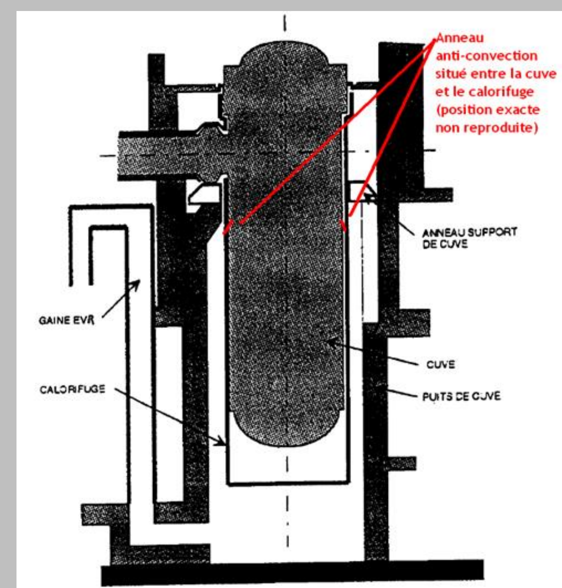
Strategy 1 was not chosen by EDF

In-vessel melt retention by external flooding

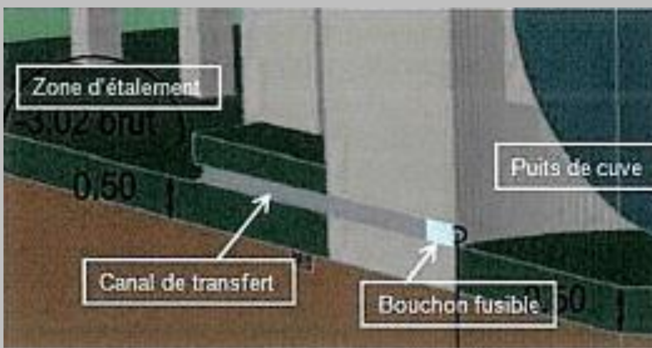
⇨ May be favorable for corium retention but the demonstration that the vessel integrity can be kept is difficult for the worst cases.

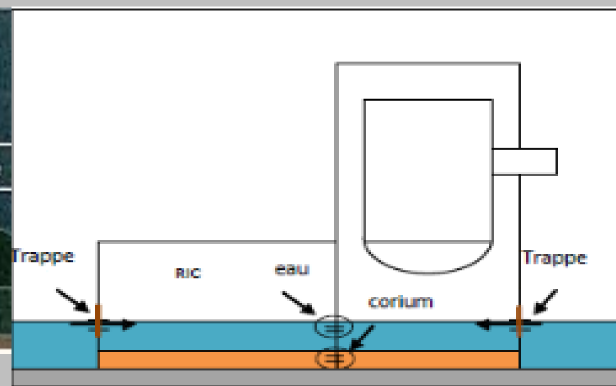
⇨ In case of vessel failure, a consequent steam explosion in the reactor cavity, with possible effect on containment (floors displacements …), cannot be excluded .

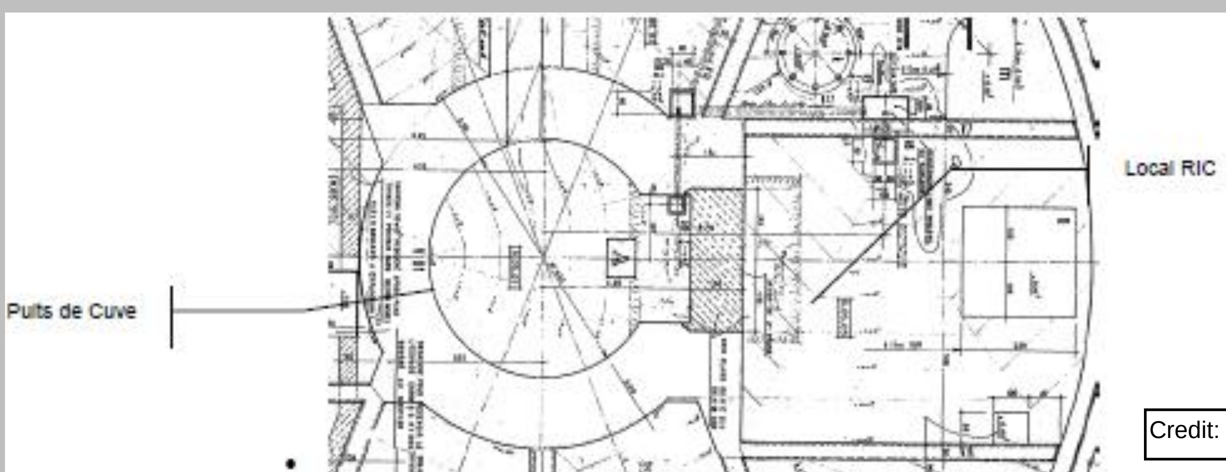




Strategy 2 has been chosen by EDF







Credit: ASN

Principles :

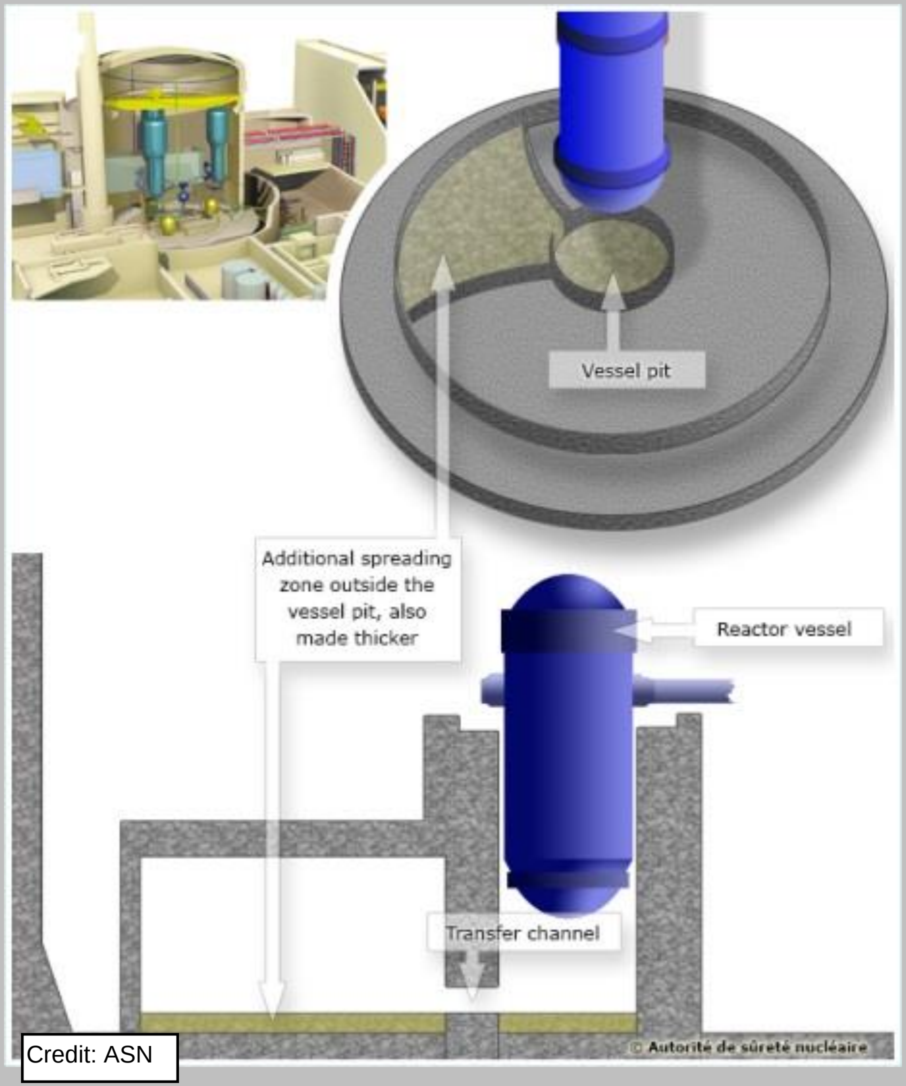
1. Dry cavity pit
2. Dry additional corium spreading zone in some cases
3. Containment sump filled with water during early phase
4. Corium spreading in the cavity pit and additional zone (if any)
5. Gravity flooding above the corium after spreading

Dry spreading

- Back fitting approach for a French reactor with a 1.5 m thick basemat
  - Larger spreading area reduces heat flux to the concrete
  - Basemat thickness increased by additional self pouring concrete layer is feasible

⇨ Melt-trough delay > 24h

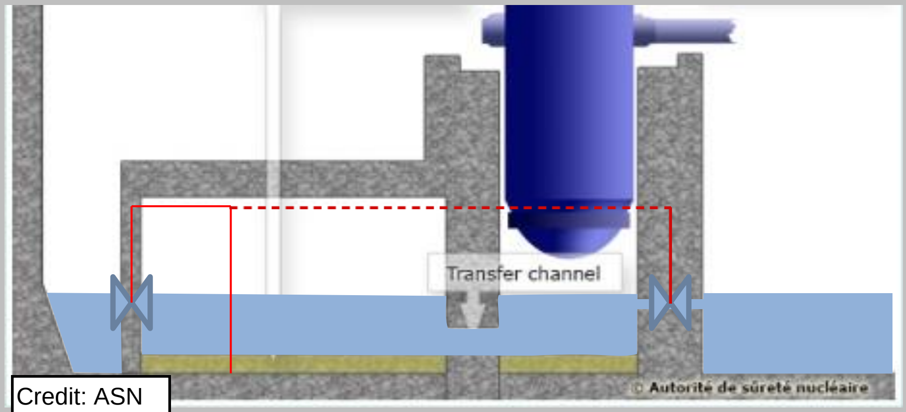
- Practical elimination of steam explosion risk



Dry spreading and early flooding

- Solution under discussion for French reactors fleet LTO
  - Equipment modification to maintain an initial dry pit
  - Additional spreading room and basemat thickness increased with high gas contain concrete depending on containment design (geometry and concrete composition)
  - Passive top flooding from sump water

⇨ Containment integrity

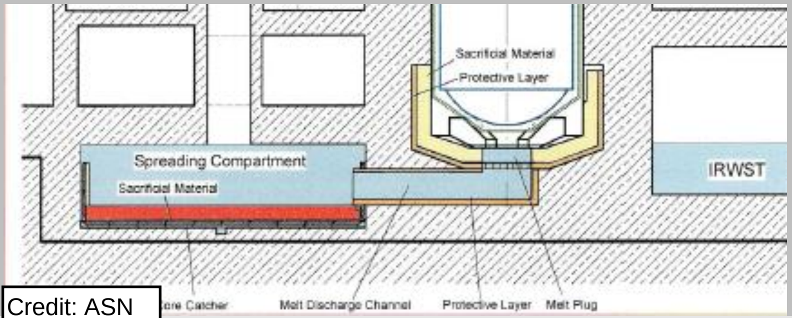


Credit: ASN

- Remaining issue
  - Uncertainties on corium pouring conditions
  - Effect of metal on cooling mechanisms

Corium cooling after corium spreading is a solution already studied in France

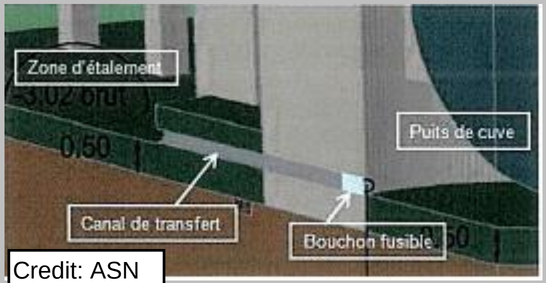
EPR Flamanville 3



Credit: ASN

Fessenheim

Dry corium spreading onto cavity pit and nearby compartment (~ 90 m²)



Credit: ASN

Modification implemented in the Fessenheim 900MWe

- Specific situation of Fessenheim NPPS already addressed by EDF
  - Reactor vessel pit thickened by self-sustained LCS-type concrete layer
  - Fusible plug open a transfer channel to a surrounding zone
  - Possible spreading in this additional zone outside the reactor vessel pit also thickened
  - Passive early flooding using sumps

✓ *Operationality of the modification procedure demonstrated for 2 plants*

French Advisory Committee conclusions on EDF proposals (July 2016)

The French Advisory Committee considers that the EDF "*proposals appear, in their principle, satisfactory to reduce the risk of corium reactor basemat melthrought*"

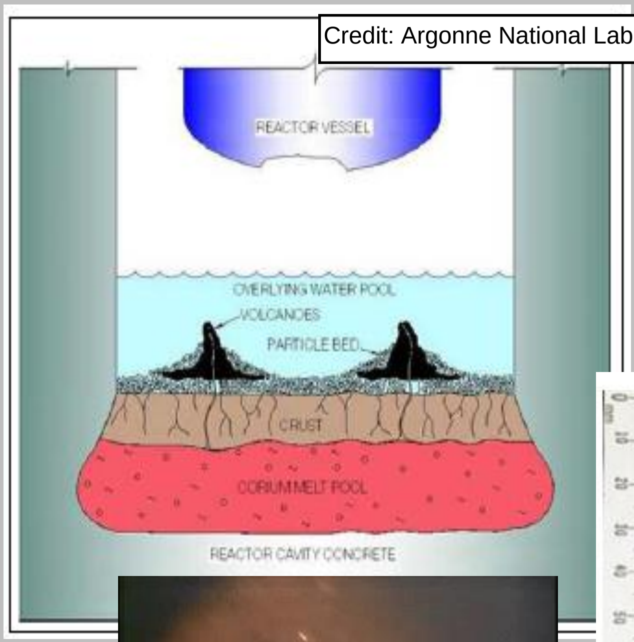
Compared to a solution based on in vessel melt retention by external vessel flooding, "*this proposals should also reduce the risk of containment failure associated to a steam explosion in the reactor pit that may result from corium flow from the vessel into water*".

Design of plants modifications is on-going by EDF and will take into account the French Advisory Committee conclusions, IRSN review and the French Safety Authority requests.

Links with R&D

MCCI under water

The corium ejection and water ingression mechanisms, in favor of corium cooling, are observed during tests of corium-concrete interaction.



Credit: Argonne National Lab.

Experimental data
→ Codes validation
→ Reactor Safety cases

Vue du dessus du volcan principal

Credit: Argonne National Lab.

... de débris

Credit: Argonne National Lab.

MCCI under water

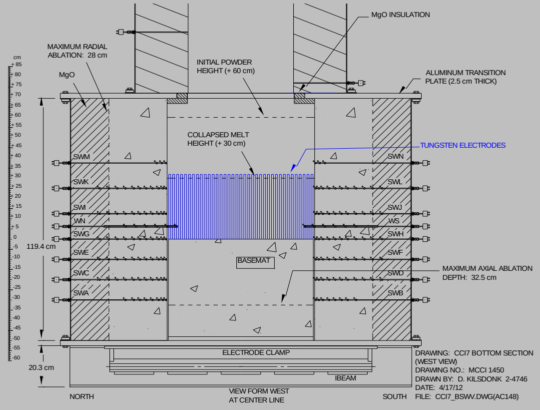
Budget : ~ 1000 k$ / test
Experiments performed by ANL
Program coordinated by EDF with international partnership

Credit: Argonne National Lab.

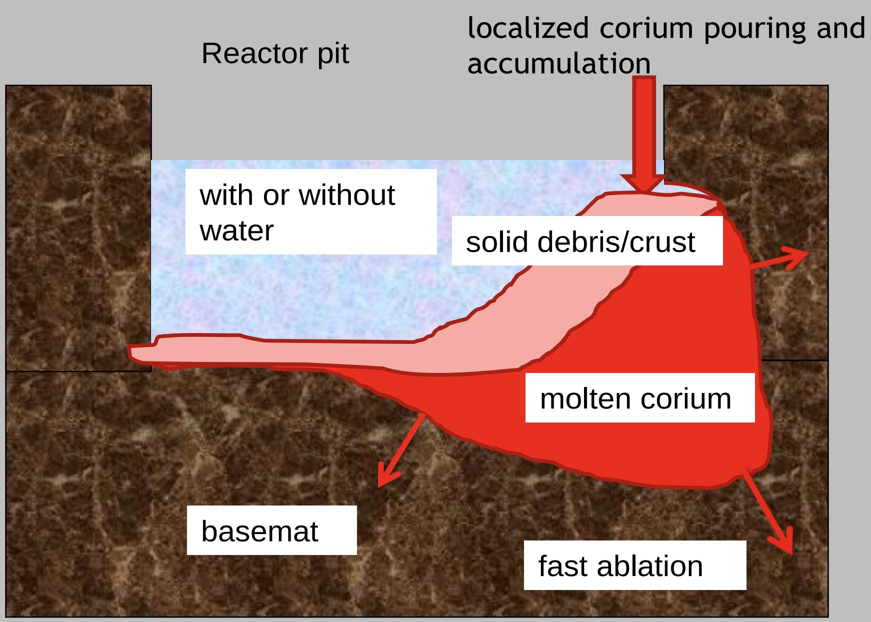
- EDF CCI program in the ANL facility (2103-20

Improve the knowledge on corium stabilization by top flooding during early phases of MCCI, effect of type of concrete (≠ gas releases)

- CCI7 (2013) with siliceous concrete suggested limited impact of melt ejection
- CCI8 (2014) with LCS concrete highlighted several transient episodes of melt eruption
- CCI9 (2016) with siliceous concrete focusing on water ingression
- CCI10 (2017) limestone rich concrete maximizing gas release to investigate possible improvement of melt ejection



Initial ex-vessel conditions

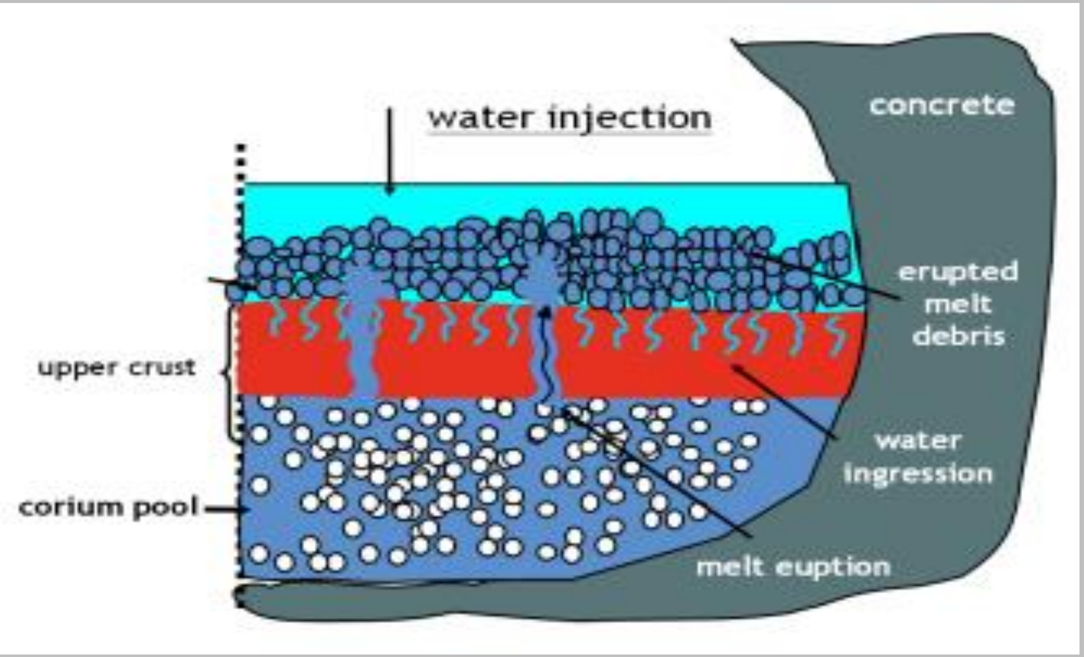


- Corium accumulation risk in presence of water in reactor pit
  - Accumulation of viscous melt under water
  - Melt fragmentation and accumulation of debris/cake in deep water pool
  - In shallow water layer

⇨ Localized faster ablation

- Corium accumulation stability?

MCCI and corium coolability

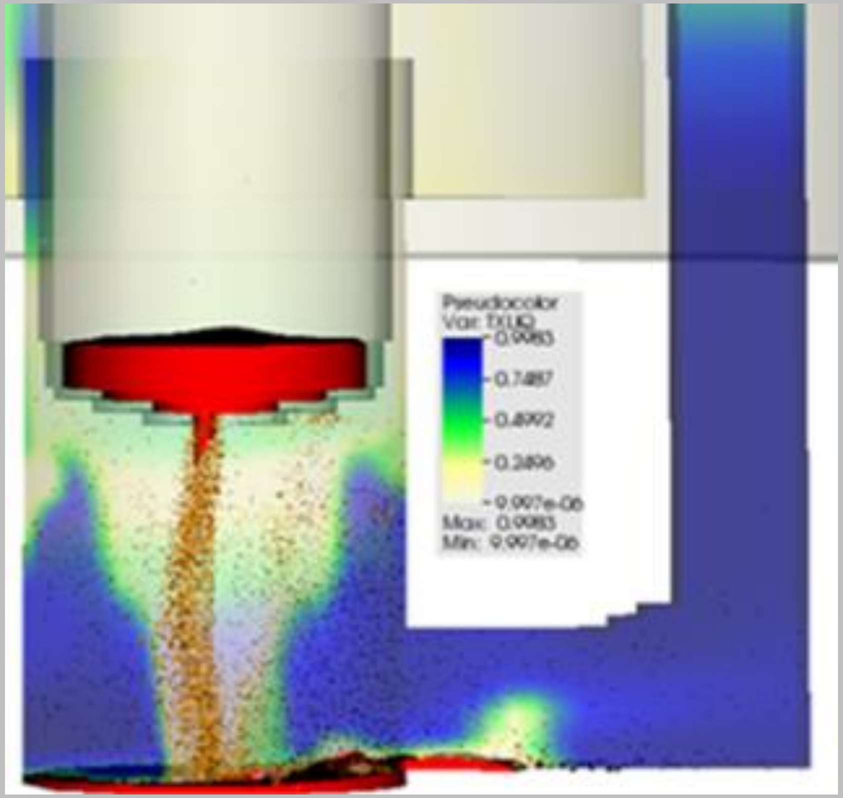


- OECD SOAR approved by CSNI in June 2016

- Dry MCCI: nature and extent of core-concrete interaction
- Melt stabilization by top flooding: efficiency of water ingression and melt ejection
- Remaining issues include specific realistic reactor conditions from short to long term, and the potential to improve the efficiency of melt coolability under top flooding conditions.

⇨ E2VR H2020 proposal…

Fuel Coolant Interaction



- Steam explosion
  - In deep water pool
  - In shallow water layer

⇨ Early failure risk for the containment?

- Corium quenching
  - Corium fragmentation process
  - Corium accumulation risk

⇨ Consequences on MCCI?

- OECD TOP almost completed