The DENOPI project:
a research program on SFP under loss-of-cooling and loss-of-coolant accident conditions

IRSN
INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

Faire avancer la sûreté nucléaire

IAEA IE8M meeting – February 2015

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IRSN / Nuclear Safety Division / Safety Research

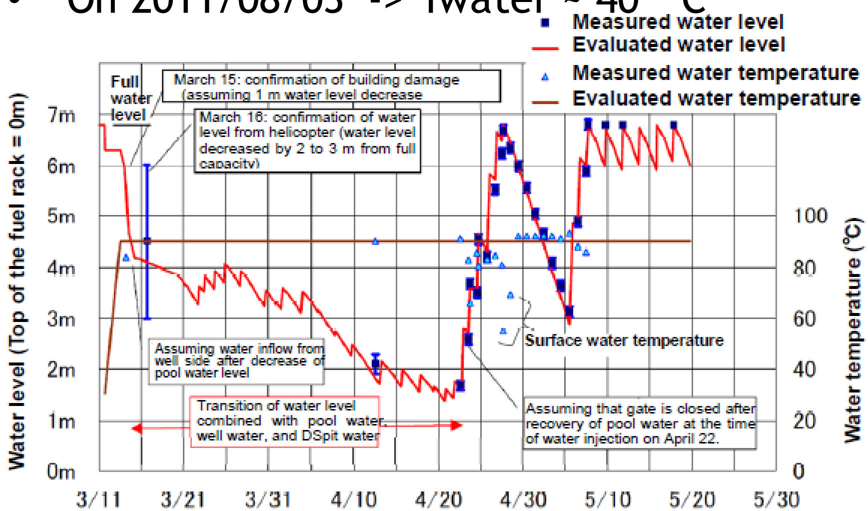
Fukushima Daiichi Unit 4 SFP (OECD Status Report on SFP – 2015)

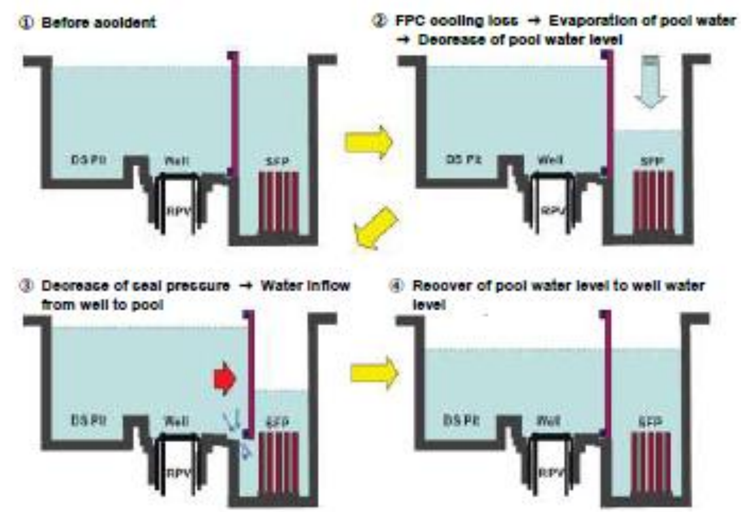
- On 2011/03/11: 1535/1590 fuel assemblies, 1331 spent fuels, 204 fresh fuels
- Decay heat: 2.26MWth

- Time estimation of fuel assembly dry out: end of March 2011

- Due to delay in maintenance, the reactor well was filled with water on March 2011
- **Pressure from the reactor well side as the SFP water level became low induced a water inflow from the reactor well to the pool**

- Intensive water injection conducted between April 22 and 27
- Twater ~ 80-90° C during ~4.5 months
- Recovery of active heat removal on 2011/07/31 @ Twater ~ 75° C
- On 2011/08/03 -> Twater ~ 40° C





2013: IRSN launches the DENOPI program within the framework of the « Investment for the future » programs funded by the French Government

Scope: Spent Fuel Pool under loss of cooling and loss of coolant accident conditions

Safety objectives:

- to study the different phases and the timing of the accident,
- to assess mitigation strategies,
- to assess safety margins.

How:

- experimental investigations,
- computer code analysis.

Schedule: 2014-2019

Partners: French academic labs

IRSN strategy = experimental investigations at three scales

A: Thermal hydraulics at the pool scale

Loss of cooling - Early phase of the accident

B: LOCA at the assembly scale

Spray efficiency – Criticality – Air ingress

C: The clad behavior under air-steam oxidation

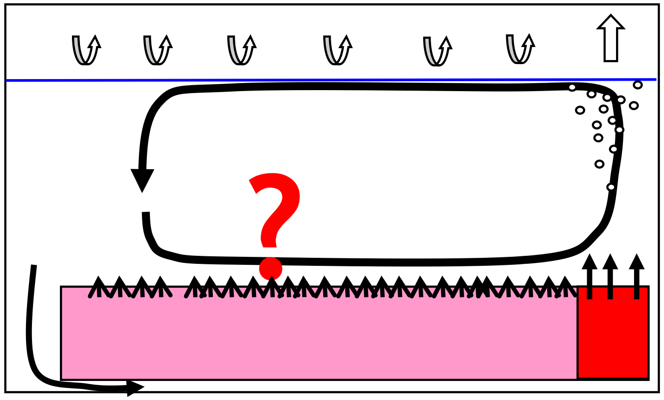
A – SFP Loss of Cooling - Studies at pool scale (1/2)

Objectives:

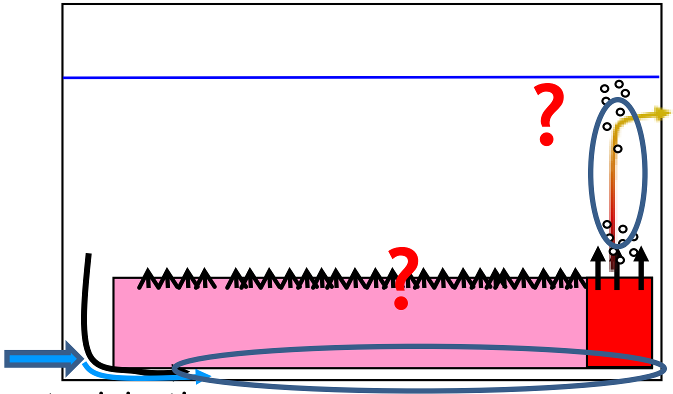
Get an experimental data base on the TH behavior of a SFP in case of a loss of cooling accident … before assembly uncovery :

- convective loop patterns and intensity ?
- influence of power distribution in the SFP ?

Validation of computer code



Patterns during loss of cooling ?
(failure of active heat removal system)

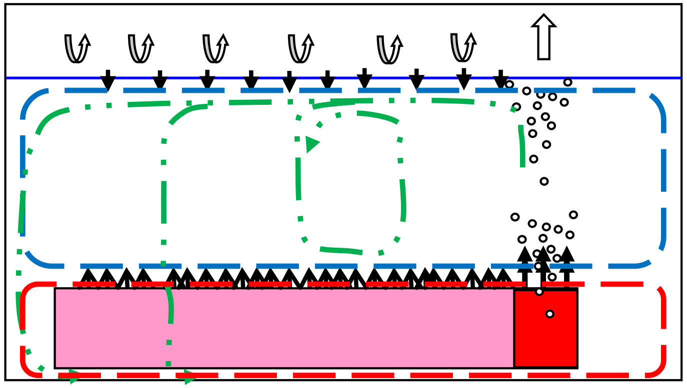


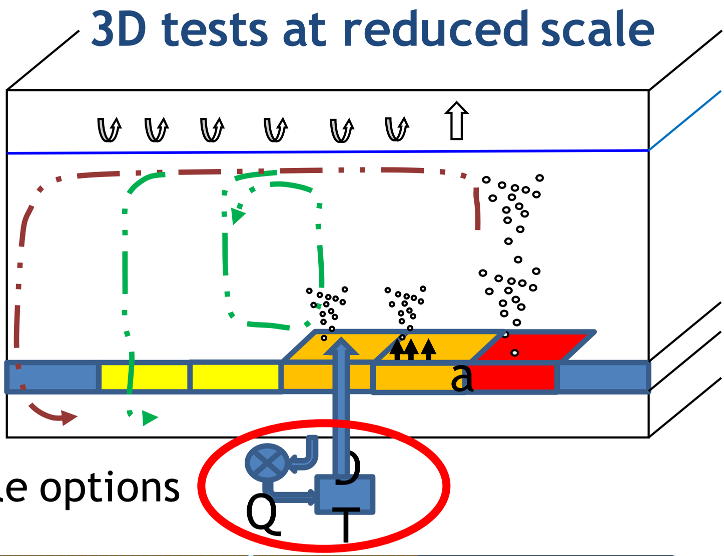
Patterns after recovery of active heat removal system

Experimental devices :

To collect experimental data on a pool mock-up at "reduced scale" for code validation

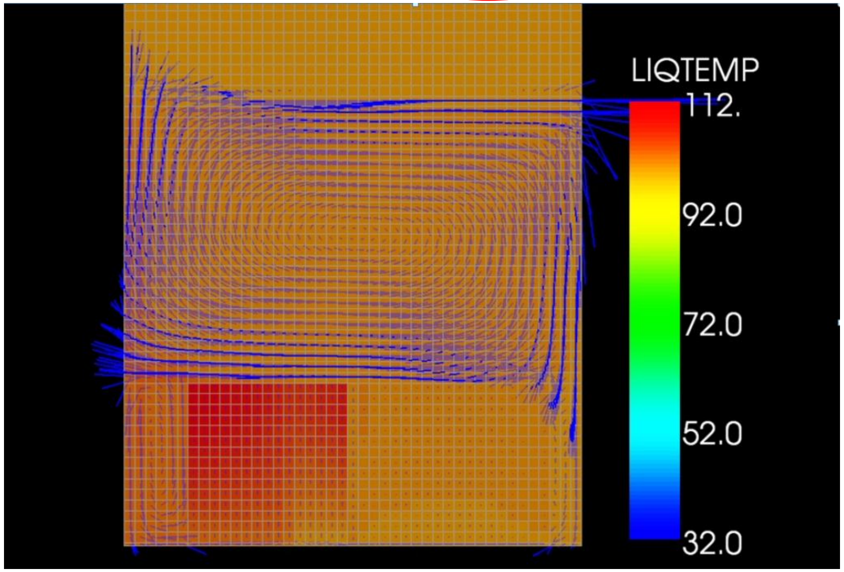
A – SFP Loss of Cooling - Studies at pool scale (2/2)





Supporting calculations - Analysis

Dimensionless numbers	SFP	Mock-up
$Re_f = \frac{\rho_f V_{fz} h_{eau}}{\mu_f}$	6,3 10^5	8,3 10^4
$Ra = \frac{g\beta\Delta T_{heau} h_{eau}^3 \rho_f}{\mu_f \alpha}$	7 10^{14}	1,6 10^{12}
$Fr = \frac{V_{fz}}{\sqrt{gd}}$	0,22	0,22
$Ja = \frac{\rho_f C_{pf}(T_{sat} - T_{pis})}{\rho_v h_{lv}}$	73	70
$Co = \frac{J_B h_{lv}}{\rho_f Cp_f \Delta T_{heau} V_f}$	0,0013	0,014



B - Studies at assembly scale (1/3)

Objectives:

1. To evaluate coolability of uncovered assemblies by water sprays — MEDEA facility

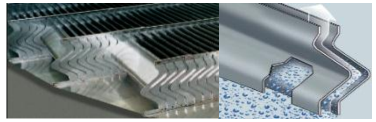
2. To evaluate criticality risk (Thermal hydraulic conditions)
3. To get knowledge on two-phase thermal-hydraulic behavior of an assembly for ≠ dewatering transients, ≠ steady-state conditions with ≠ water levels

— ASPIC facility (objectives 2 and 3)

4. To evaluate conditions for air penetration into the assembly — Dedicated small scale device

B - Studies at assembly scale (2/3): MEDEA device

1- Flooding studies:



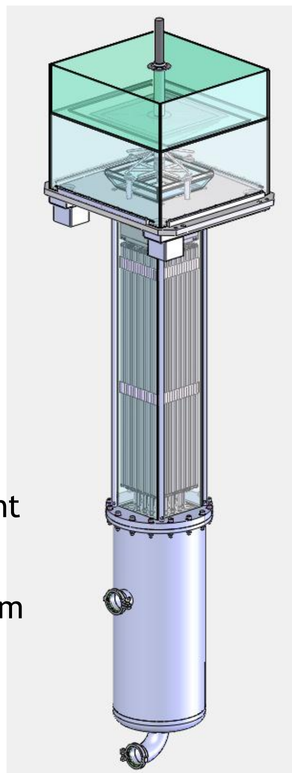
Water/air separator

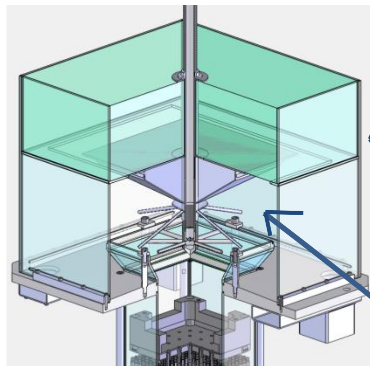
Water injection

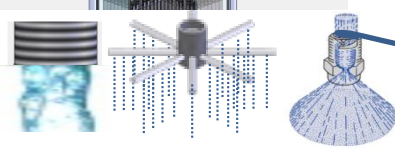
17*17 unheated rod bundle

Transparent walls

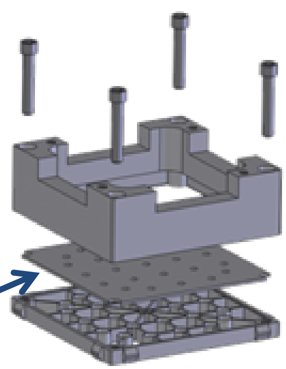
Air / steam inlet





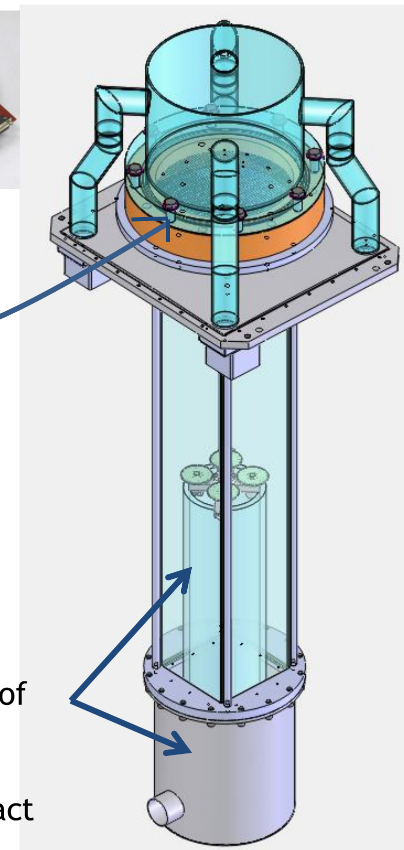


Simulation of various water injection systems [0 – 1 m^3/h]



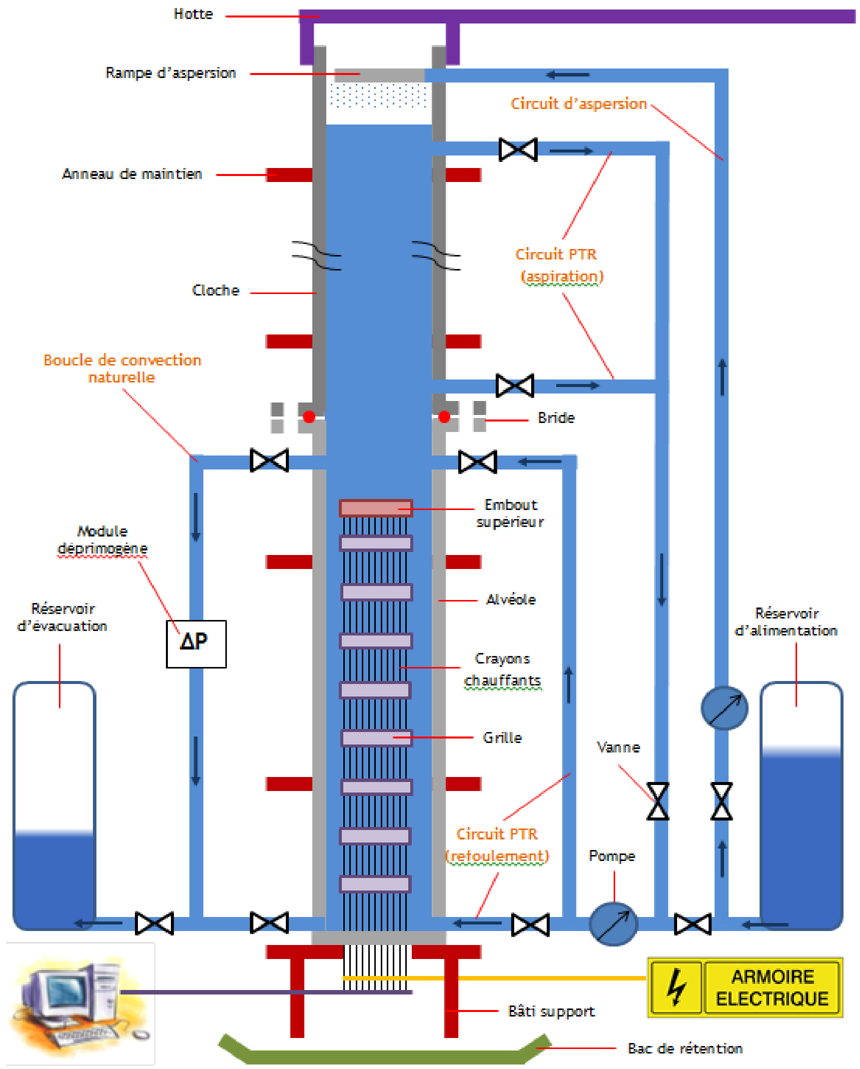
Simulation of various top nozzle geometries

2- Wire mesh sensor qualification (void fraction measurement):



Flow nozzle (minimal size of bubbles, void distribution, assembly impact on void distribution…)

B - Studies at assembly scale (3/3): ASPIC device



TH behavior of an assembly for ≠ dewatering transients, ≠ steady-state conditions with ≠ water levels, ≠ residual powers…

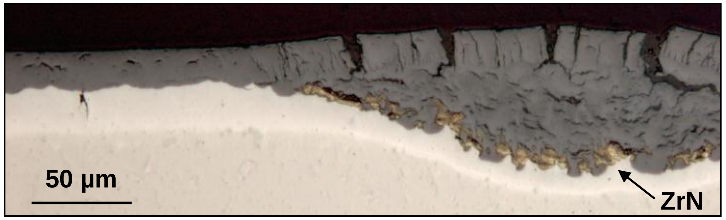
≈ 12 m

C - Studies at clad scale (1/2)

Objectives:

1. Gain knowledge on the phenomenology of the oxidation process for pre-oxidized cladding in air + steam mixtures → to develop a kinetic model that takes into account P_{O2}, P_{H2O}, P_{N2} for SA code (ASTEC)

   - how protective is the pre-transient oxide?

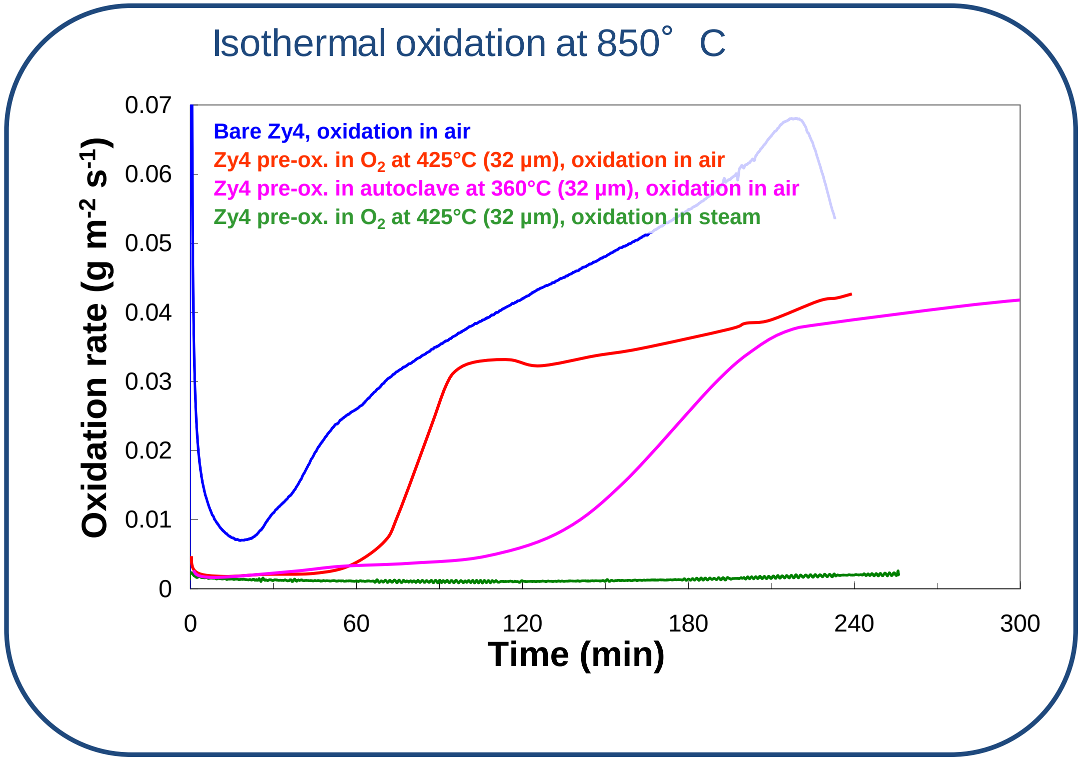


   - effect of steam addition (H-pickup) ?

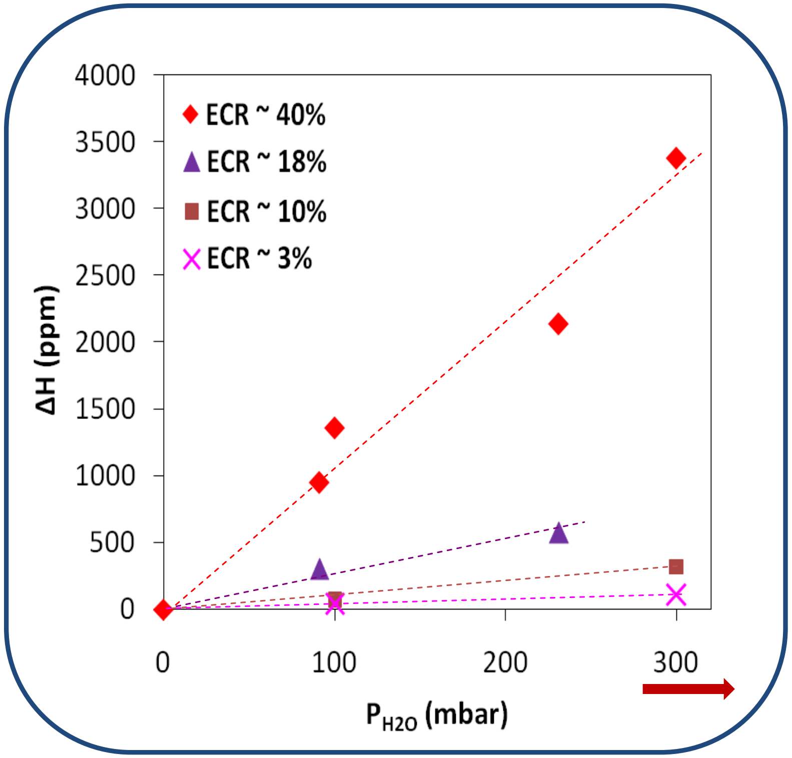
2. Mechanical properties of the cladding after an oxidation transient in air + steam (post-accident handling) :

   - how brittle are the fuel rods after accidental partial uncovery transient ?

C - Studies at clad scale (2/2) – steam partial pressure impact



C. Duriez et al. Fontevraud 8 - Avignon 2013, Septembre 14-18



IRSN, unpublished results

- HT oxidation in air is **much faster** than in steam, due to formation of ZrN and its oxidation
- A pre-oxide scale formed at low T **delays** the air attack at high T.
- The protective effect depends on the pre-oxidation method. However **acceleration due to nitriding still occurs**.
- Addition of steam in the air induces **H-pickup** during the HT oxidation. H pick-up increases with the steam partial pressure.

DENOPI Schedule