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COAL EXPERIMENTS INVESTIGATING THE REFLOODING OF A 7 X 7 RODS BUNDLE DURING A LOSS OF COOLANT ACCIDENT THERMALHYDRAULICS RESULTS

Georges REPETTO – Project Manager

Georges.repetto@irsn.fr

Participants : Q. Grando, B. Bruyère, S. Eymery



Content of the presentation

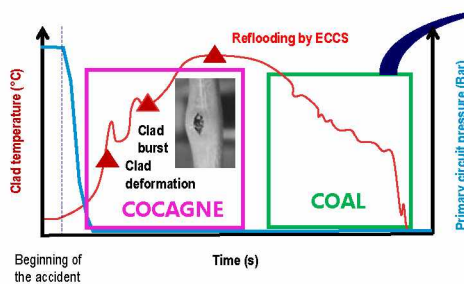
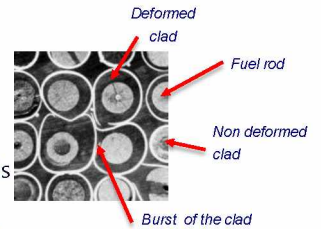
- Context of the PERFROI project
- Objectives of the COAL experiments
- Facility and COAL tests device
- Tests matrix (parameters conditions)
- Main results
- Conclusion

Context Loss-Of-Coolant Accident (LOCA)

One of the design-related accidents of a Pressurized Water Reactor (PWR)

Causes and consequence

- Pipe rupture in the primary circuit (large or Medium break LOCA)
- Vaporization of the water (drying) → Strong reduction of the cooling
- Increase of the temperature of fuel cladding → Deformation and rupture of the rods



Safety Action
Cooling the core of the reactor:

Reflooding by the Emergency Core Cooling System (ECCS)

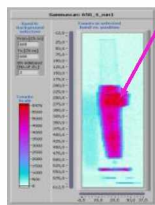
Thermomechanical aspect
COCAGNE experiments

Thermohydraulic aspect : COAL experiments

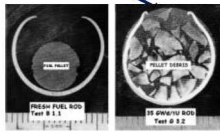
IRSN has launched the R&D PERFROI project with two axis

Objective of the COAL experiment

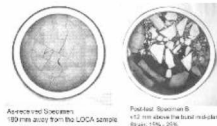
To improve knowledge / modeling of reflooding process of a fuel-rod assembly with a partially blocked area and relocated fuel simulation (taking into account the local power increase in the balloons)



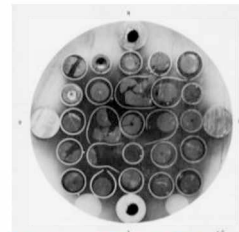
Halden test (90 GWd/t) (2006)



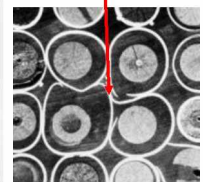
FR2 tests (35 GWd/t) (1983)



ANL tests (55 GWd/t) (1983)



Phebus LOCA 215R test (1983)

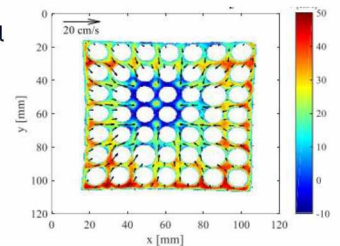


Phebus LOCA

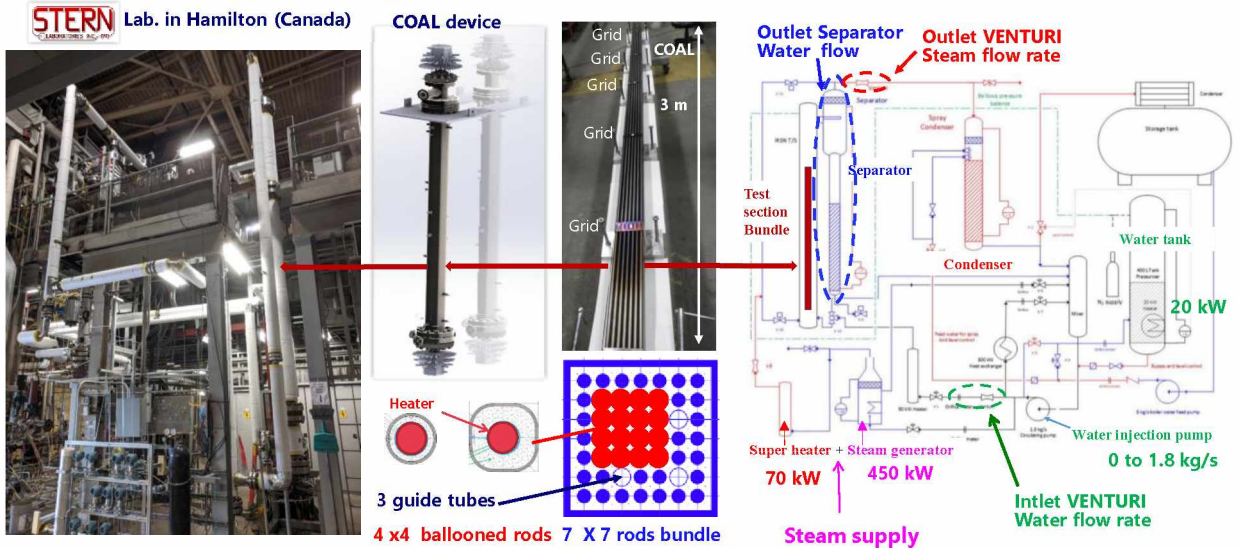
Opposing influences due to the presence of a blockage will be evaluated through an integral experiment in a bundle geometry at the full length scale.

→ On one hand, the reduction of the section between the deformed fuel rods will increase the flow velocity and the potential increase of heat transfers.

→ On the other hand, the flow bypass from the blocked area to the intact rods (cross-flow phenomena) will lead to a reduction of mass flow in the sub channels of the blockage and therefore the decrease of the heat transfers.

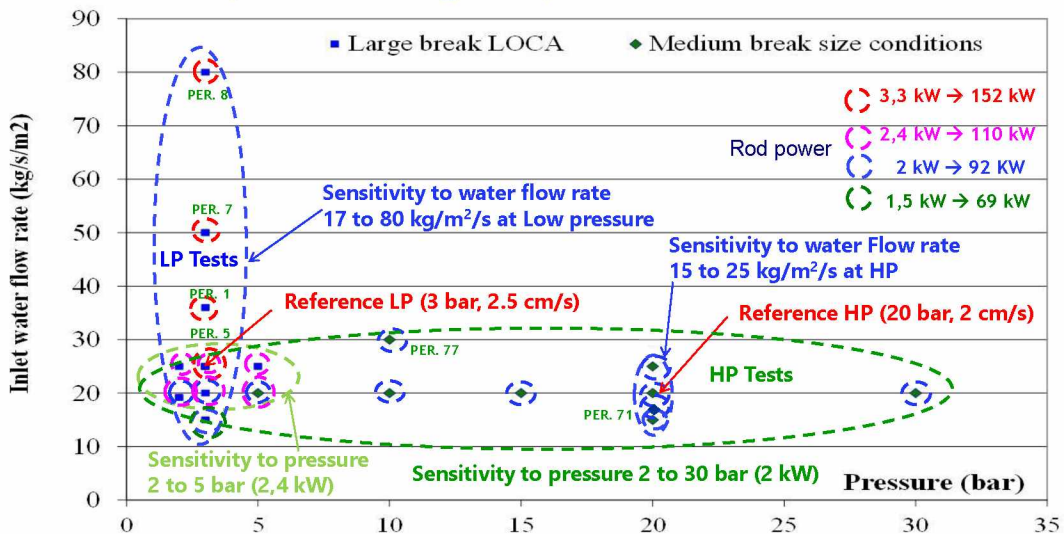


Reflooding facility and COAL tests device



→ In order to analyse the reflooding, specific efforts were done on the instrumentation (roughly 300 Tc's) and in particular with the inlet/outlet flow measurements

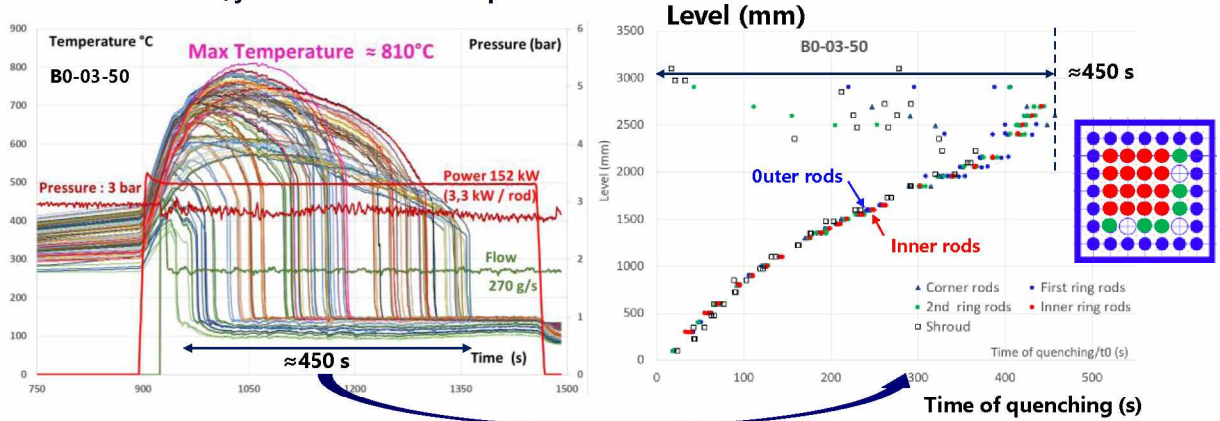
Tests matrix (as P, Q diagram)



Roughly 25 experiments was enough in order to investigate the different physical main inlet parameters (power, pressure and water flow velocity).

Typical results for Low pressure test (Large break conditions) (1/3)

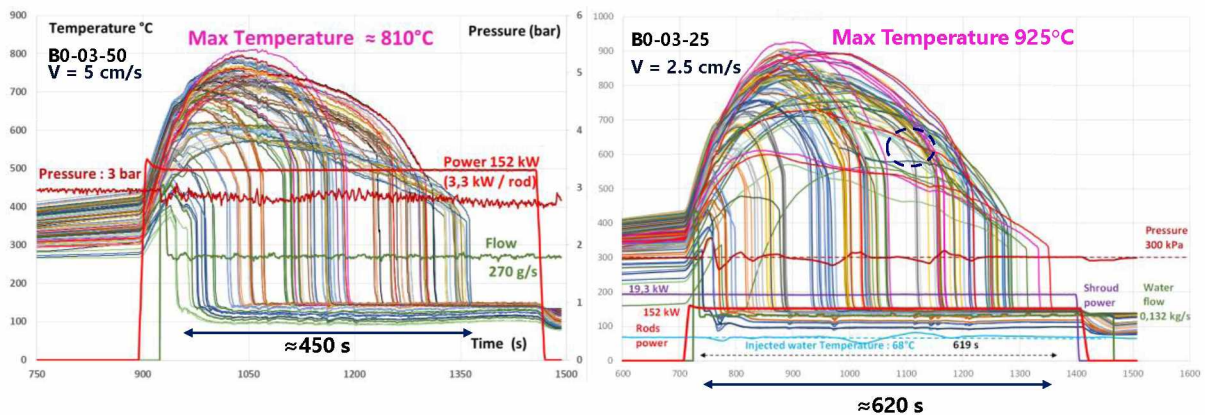
For rather high water flow rate, the maximum temperatures was recorded around 810°C on the inner rods at level 1650 mm, just above the middle plan



→ The numerous thermocouples (≈ 300) allow the determination of the quench front propagation (QFP)

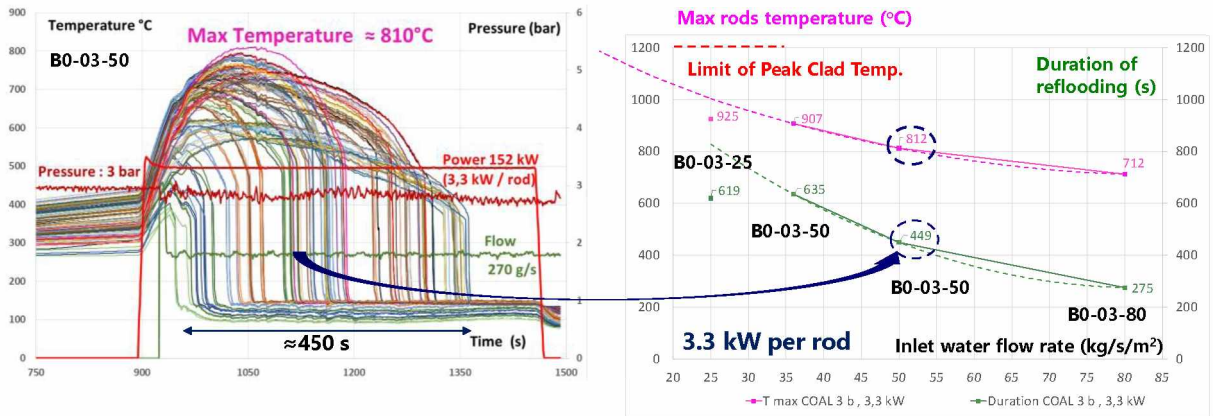
→ For intact geometry, the quench front propagations (QFP) look rather similar for all rods rings

Typical results for Low pressure test (Large break conditions) (2/3)



Typical results for Low pressure test (Large break conditions) (3/3)

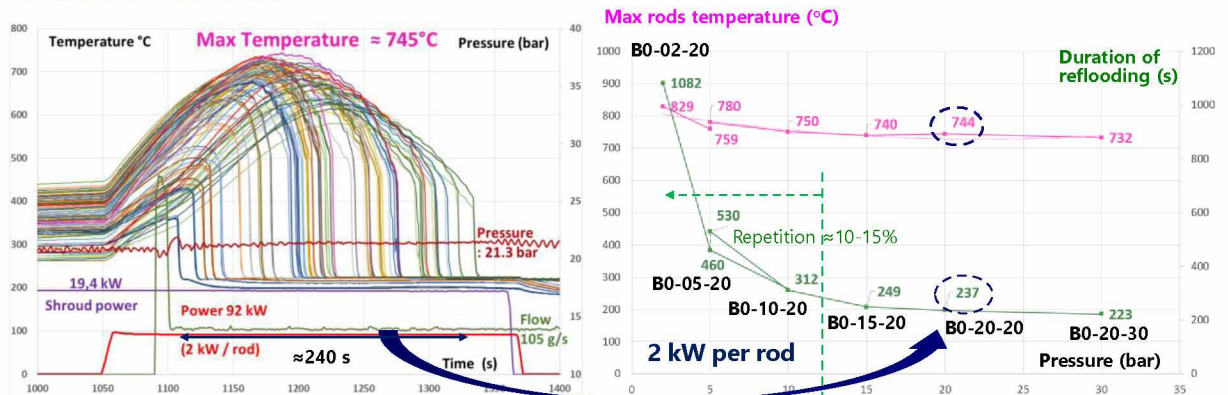
→ Those results allowed the determination of the minimum water flow rate conducting to PCT under the LOCA criteria which is fixed up to now at 1204°C (2200°F) to insure "core coolability" for intact geometry



→ As foreseen, the increase of the water flow rate reduces the time for complete "reflooding" whereas the decrease of the flow rate leads to higher duration as well as higher Peak Cladding Temperature (PCT)

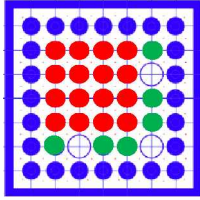
Typical results for High pressure test (Medium break conditions)

For the reference HP test, the maximum temperatures was recorded around 750°C on the inner rods far below the LOCA criteria

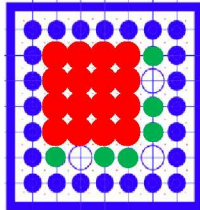


→ Above 15 bar up to 30 bar, we do not observe any variation of the duration of the reflowing, whereas the reduction of the pressure below 15 bar lead to a strong increase of the duration with a less and less efficiency of the reflowing process in particular below 5 bar

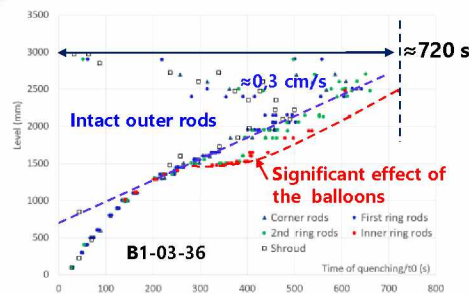
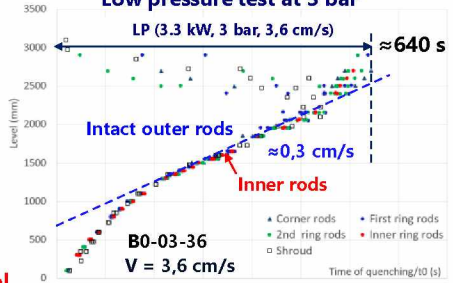
Quench front propagation



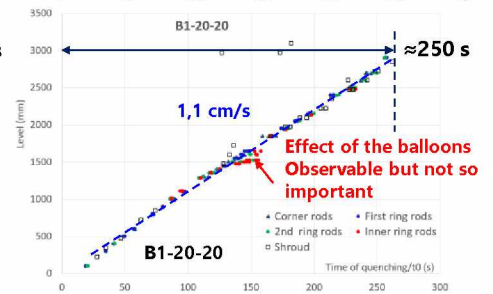
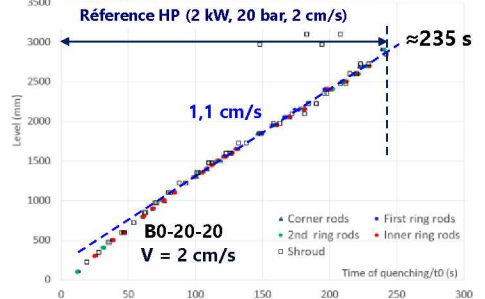
→ The second B1 experimental campaign including a partially blocked area was performed more recently : mid of 2021



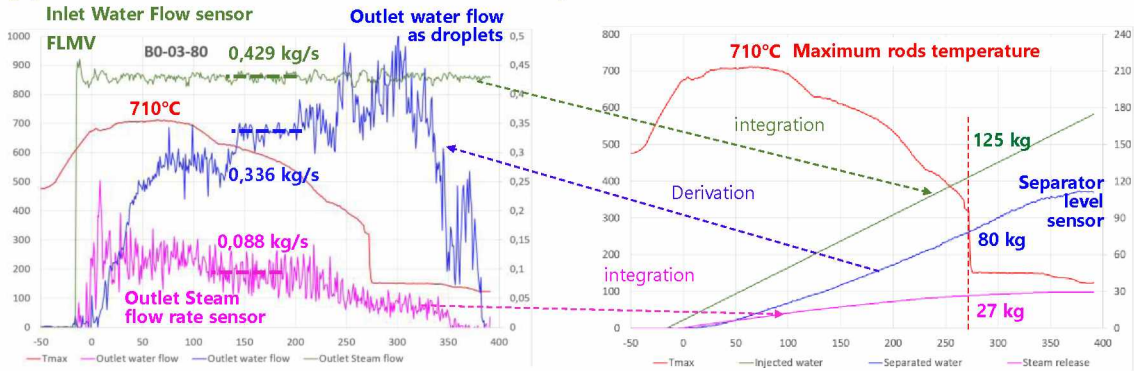
Large break LOCA scenario (40") Low pressure test at 3 bar



Medium break LOCA scenario (5") High pressure test at 20 bar



Typical Flow rate results for low pressure test (LB-LOCA)



The total amount of water injected and steam produced during the reflooding are obtained by the integration of the signals given by inlet water flow sensor and steam flow rate sensor

The instantaneous water flow rate at the outlet of the bundle (mainly as droplets) is obtained by the derivation of the cumulative value of water collected in the water/steam separator

When the quench is completed, the water balance (= 125 kg – 80 kg – 27 kg) is consistent with the amount of water to fill the bundle which outline high confidence on the flow rate results

In addition to thermocouples results, water/steam flow measurements (available for the COAL experiments) are useful to validate and improve thermal hydraulic modelling of the “reflooding” processes

Conclusion

- 25/30 COAL experiments (**First B0 campaign : intact rods in 2020**) was performed to investigate the different physical main inlet parameters such as the power per rod (**1.5, 2, 2.4 and 3.3 KW**), the pressure (ranging from **0.2 to 3 MPa**) and the inlet water flow velocity : **ranging from 17 (1.7 cm/s) to 80 kg/s/m² (8 cm/s)**
- The maximum temperature (**925°C**) was obtained during the test performed at low pressure (0.3 MPa) with the maximum power per rod (**3.3 kW**) and a medium water flow rate (**25 kg/m²/s – 2.5 cm/s**)
- We succeeded to perform high pressure experiments from 1 up to 3 MPa which was one of the major objective of the COAL experiments in order to investigate the coolability for Medium Break LOCA condition : **it appears that reflooding processes are more efficient at high pressure above 1 MPa.**
- The **B1 campaign** with a 7 x 7 bundle including partially blocked area with ballooned rods (**length 100 mm , blockage ratio at 80%** and **local power increase : x 1.5**) was performed **mid of 2021** : we clearly see the effect of the balloons which increased the **Peak Cladding Temperature up to 1105°C** mainly at low pressure
- The next **B2 COAL campaign** is foreseen by mid of 2022 with similar bundle including larger blocked area (**length 300 mm and 90% blockage ratio**) considered as the worst case
- The results of **COAL experiments** will provide **thermal hydraulic data** needed to **improve** the codes **modelling during the reflooding under LOCA sequence** : **work under process at IRSN with our own DRACCAR code**

Thank for you attention

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