

IRSN

INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Enhancing nuclear safety

Experimental study of an adiabatic two-phase flow in a simulated PWR spent fuel bundle

G. Brillant, J. Martin and B.
Fourré

IRSN, PSN-RES

#27425 - NURETH 18 - August 18-23 2019

MEMBER OF

ETSON

EUROPEAN
TECHNICAL SAFETY
ORGANISATIONS
NETWORK

Contents

- Elements of context
- MEDEA facility
- MEDEA overflow test series
- Conclusion

Elements of context

Spent Fuel Pool accidents

- High fission product inventory due to several cores storage
- Fukushima Daiichi Unit 4 SFP-LOCA
 - ~2.3 MW
- International effort on SFP accidents
 - deep assessment of the safety of existing SFP in several countries
 - increase of the research activities for SFP safety in numerous institutes and Universities
 - OCDE reports: status report on SFP LOCA accidents and Phenomena Identification and Ranking Table (PIRT) on SFP accidents

The DENOPI project

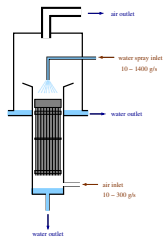
- **A research program on SFP loss-of-coolant and loss-of-cooling accidents**
 - experimental investigations
 - computer code analysis, development, and validation
- **Safety objectives:**
 - to study the different phases of the accident
 - to assess mitigation strategies
 - to assess safety margins
- **Leader: IRSN - Partners: US-NRC, Bel-V, EdF, French University labs**
- **Schedule: 2014-2021**

3 spatial/temporal scales within the DENOPI project

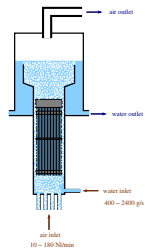
- **Integral SFP scale / prior to fuel uncovering**
 - investigation on large natural circulations loops, bubble production by boiling/flashing, ...
- **Bundle scale / during the assemblies uncovering**
 - thermal-hydraulic behavior during boil-off or draining
 - assessment of the cooling efficiency of a spray system
- **Clad scale / after rod uncovering**
 - investigation on the oxidation of pre-oxidized cladding materials exposed to steam/air mixtures
 - development of oxidation kinetic models for system codes

DENOPI: the bundle scale experiments

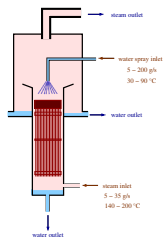
MEDEA v1 flooding



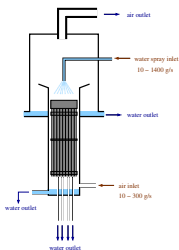
MEDEA v1 overflow



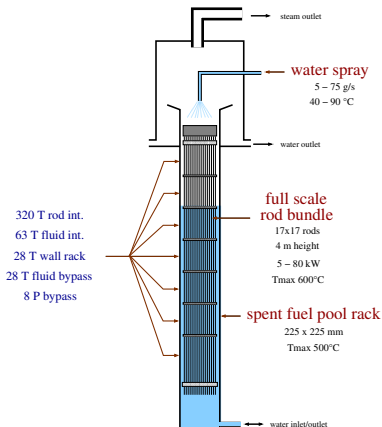
MEDEA v2 steam



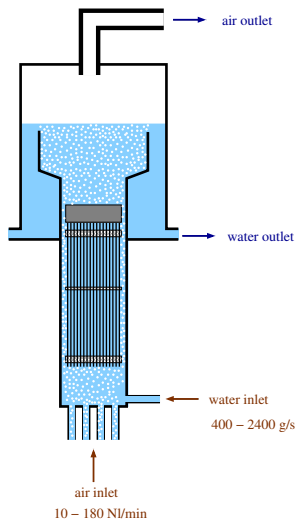
MEDEA v2 air



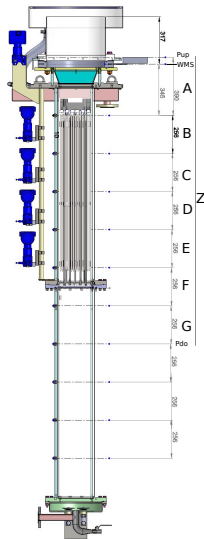
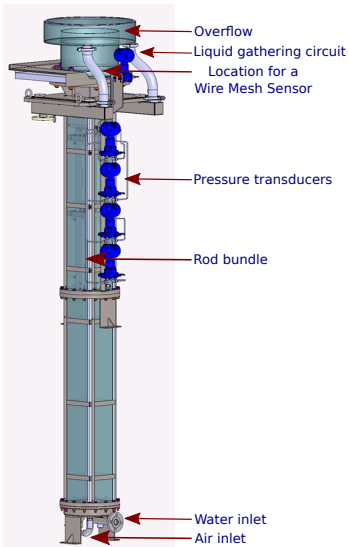
ASPIC



MEDEA overflow experiments



- One meter height rod bundle
 - Co-current upward air/water flow
 - Water flowrate in the range of the expected natural circulation in SFP
 - Pressure loss and void fraction measurements
- ➔ experimental data for codes development and validation
- ➔ e.g. drift flux model for system codes



Prototypical PWR assembly

- rods
- grids
- top nozzle

Measurements

- air flowrate
- water flowrate
- differential pressure (x7)
- absolute pressure (x2)

MEDEA overflow

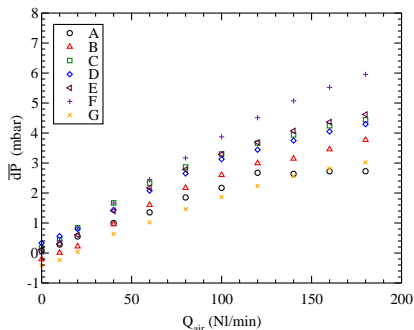
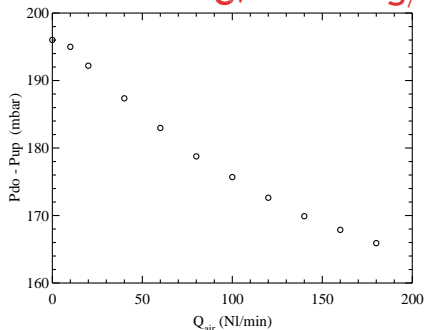
Parameters

- **water mass flowrate**
 - 400, 800, 1200, 1600, 2000 and 2400 g/s
- **air volume flowrate**
 - 0, 10, 20, 40, 60, 80, 120, 160 and 180 NL/min
- **with / without the rod bundle**

Protocol of a test series

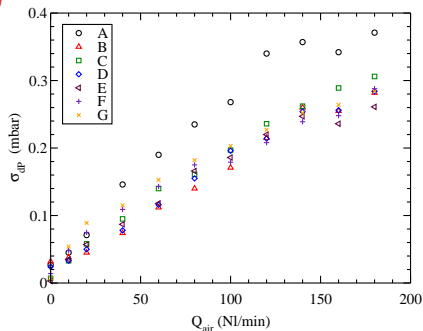
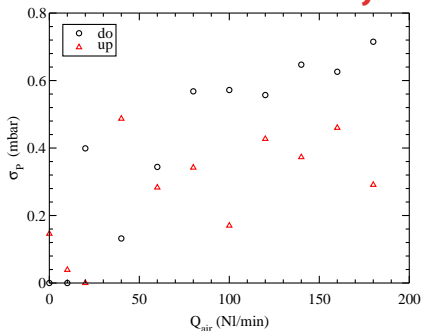
- **the water mass flowrate is kept constant**
- **the air flowrate is increased step by step from 0 NL/min to 180 NL/min**
- **at each air flowrate value:**
 - the stabilization of the flow is awaited
 - the measurements are performed over 10 min at 1 Hz

Pressure at $Q_w = 1200 \text{ g/s}$ with the bundle



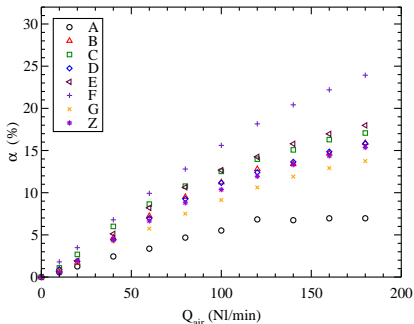
- **Maximum variation of**
 - ~ 30 mbar over the full height (uncertainty 1.5 mbar)
 - ~ 6 mbar over intermediate height (uncertainty 0.05 mbar)
- **Measurements at $Q_{air} = 0$ NL/min**
 - reference state of the transducers
 - offset for the calculation of the void fraction

Standard deviation of the pressure



- No clear pattern on the absolute signal
- Linear evolution of σ_{dp} for $Q_{air} < 140$ NL/min
- Altered behavior for $Q_{air} > 140$ NL/min
 - ➔ flow regime change at $Q_{air} \sim 140$ NL/min
- More perturbed flow over the rod bundle (curve A)

Void fraction with the rod bundle



- **In the assembly**

- intermediate values
- no clear impact of the grids

- **Above the assembly (A)**

- smaller values due to enlargement of the section / recirculations
- stabilization at $\sim 7\%$

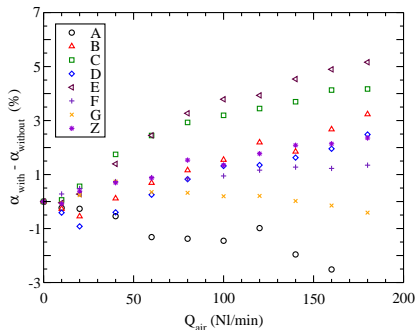
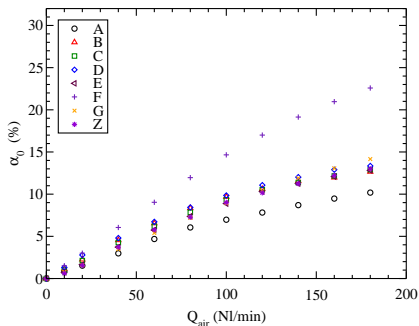
- **Just below the bundle (F)**

- higher values due to a plug at lower plate

- **Below the bundle (G)**

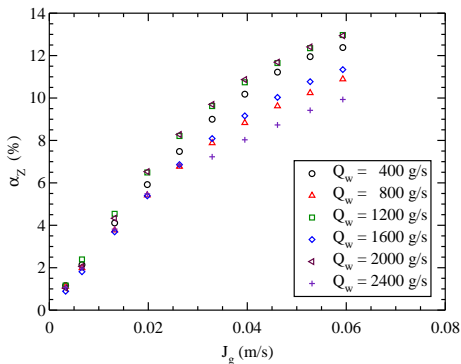
- smaller values due to smaller frictions

Void fraction without the rod bundle



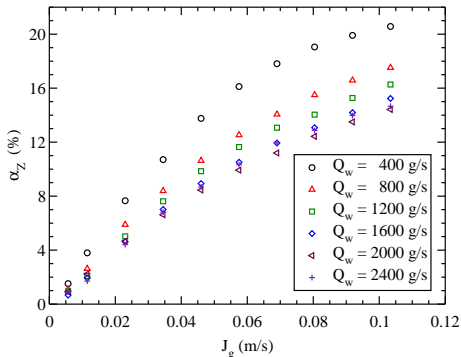
- Still smaller values above the section (A) and higher below the lower plate (F)
- Cluster for B-C-D-E-G (no bundle)
- Differences with/without bundle increase with air flowrate (↗ frictions)
- No clear impact of the grids

Test series without the bundle



- **At low gas friction velocity J_g**
 - bubbly flow
 - almost no impact of the water velocity/flowrate
- **At high gas friction velocity**
 - flow macroscale patterns
 - no clear impact of the water velocity/flowrate

Test series with the bundle



- At low gas friction velocity $J_g < 0.05$ m/s → bubbly flow
- At high gas friction velocity
 - cap-bubbly flow
 - slug flow at the top nozzle level
 - flow macroscale patterns
 - clear impact of the water velocity/flowrate (at low Q_w)

Conclusions

- SFP loss-of-cooling/coolant accidents
- MEDEA overflow experiments
 - co-current air/water flow
 - one meter height bundle in a SFP rack
 - Pressure / void fraction measurements
 - no clear impact of the grids on void fraction profiles
 - several flow regimes (bubbly, cap, slug flows)
- Data for model development/validation
 - e.g. drift model for system codes
- Perspectives: the ASPIC facility
 - four meter high 17x17 heated rods bundle
 - steam/water flows with boiling