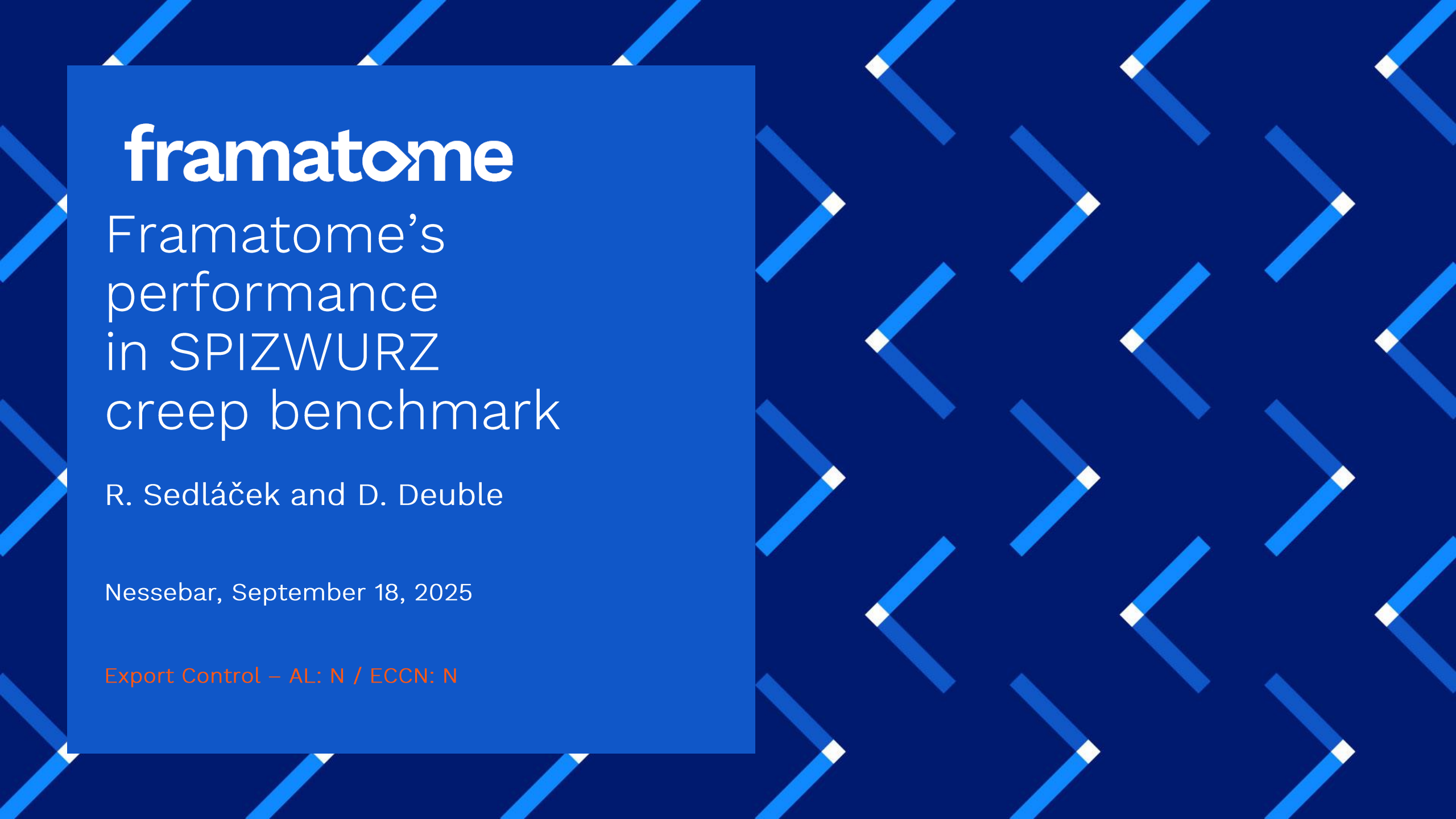




framatome

Framatome's performance in SPIZWURZ creep benchmark

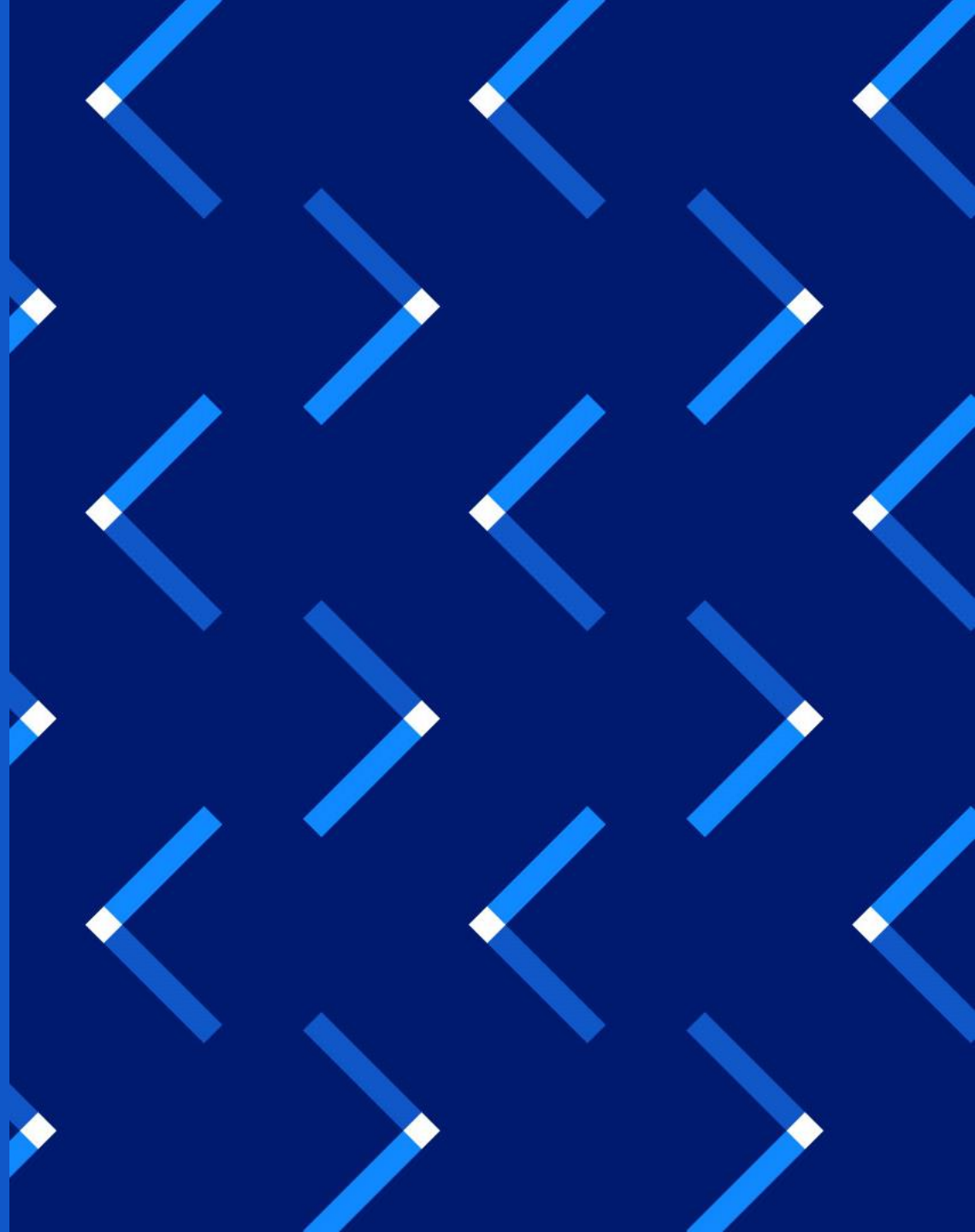
R. Sedláček and D. Deuble

Nessebar, September 18, 2025

Export Control – AL: N / ECCN: N

Content

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2. Framatome creep model
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4. Conclusions
5. Acknowledgements



1

SPIZWURZ creep benchmark

SPIZWURZ creep benchmark

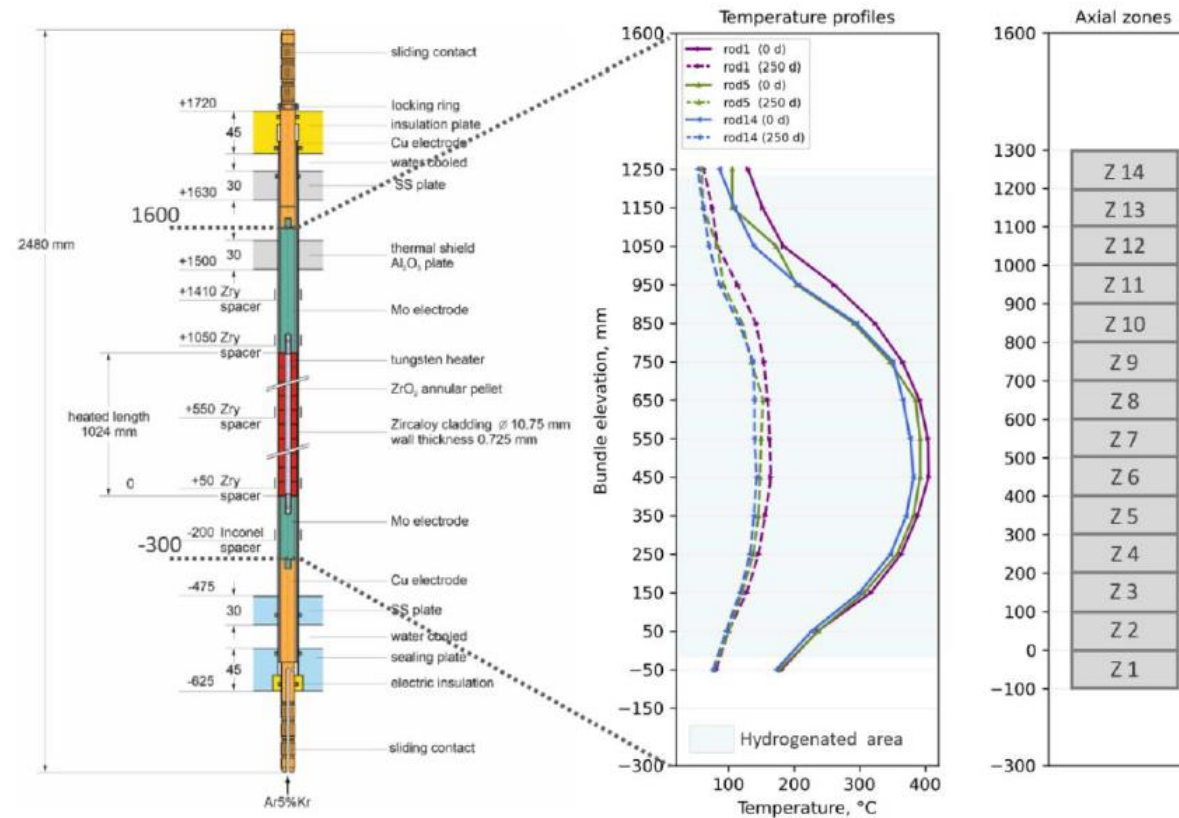


Fig. 2.3 Axial temperature profiles at the beginning and the end of the experiment (middle). Axial zone layout for the benchmark (right). Fuel rod simulator (left).

Rezchikova, Stuckert. SPIZWURZ Benchmark, Phase 1, Specification v.3, July 2024, GRS.

SPIZWURZ creep benchmark

Framatome creep simulations:

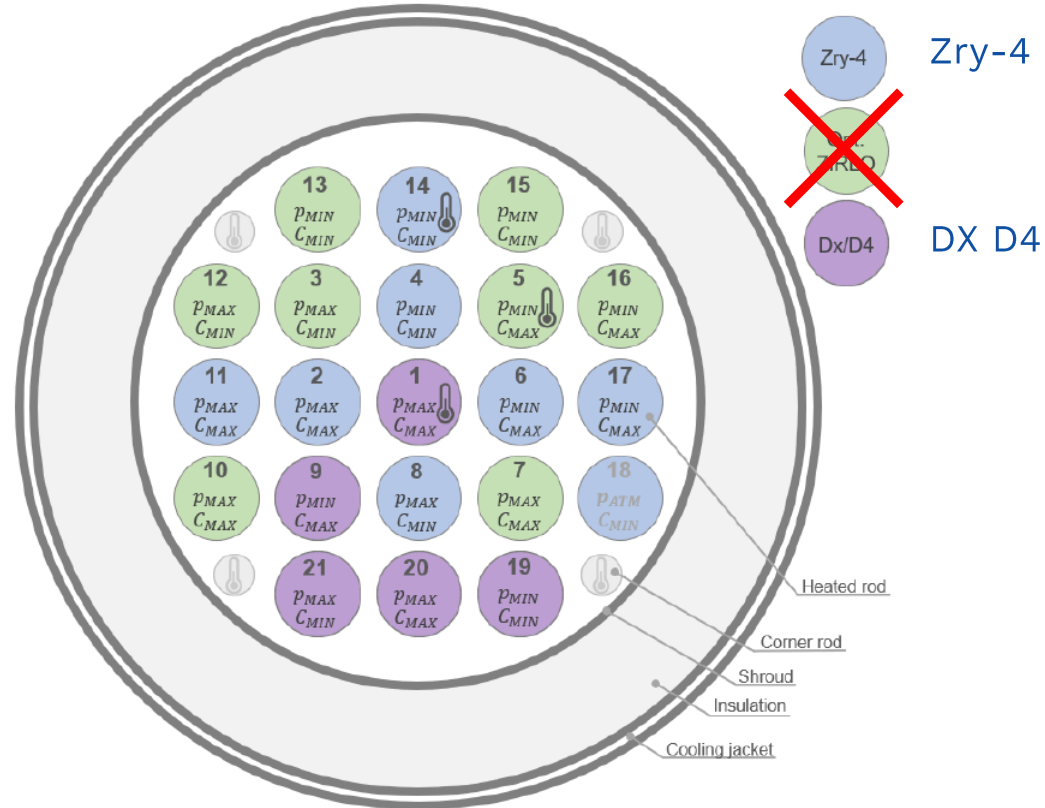


Fig. 2.2 SPIZWURZ test bundle (top view). Thermocouple instrumentation.

Rezchikova, Stuckert. SPIZWURZ Benchmark, Phase 1, Specification v.3, July 2024, GRS.

2

Framatome creep model

Framatome creep model

Fuel rod design calculations for dry storage

proceed in two steps

1. Normal operation in reactor
 - Fuel Rod Design (FRD) code CARO-E
 - End Of Life (EOL) state of the fuel rods
2. Dry storage / transportation
 - FRD code CSAS
 - Maximum cladding hoop stress
 - Maximum cladding creep strain

SPIZWURZ benchmark

- CSAS R&D
- Cladding creep strain in the axial zones
- Independent temperature and pressure inputs

Framatome creep model



Nuclear Technology



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Thermal Creep Model for CWSR Zircaloy-4 Cladding Taking into Account the Annealing of the Irradiation Hardening

Chantal Cappelaere, Roger Limon, Christelle Duguay, Gérard Pinte, Michel Le Breton, Pol Bouffieux, Valérie Chabretou & Alain Miquet

To cite this article: Chantal Cappelaere, Roger Limon, Christelle Duguay, Gérard Pinte, Michel Le Breton, Pol Bouffieux, Valérie Chabretou & Alain Miquet (2012) Thermal Creep Model for CWSR Zircaloy-4 Cladding Taking into Account the Annealing of the Irradiation Hardening, Nuclear Technology, 177:2, 257-272, DOI: [10.13182/NT12-A13370](https://doi.org/10.13182/NT12-A13370)

To link to this article: <http://dx.doi.org/10.13182/NT12-A13370>

Framatome creep model

Model equations

1. Creep strain rate as a function of

- Temperature (Arrhenius)
- Stress (sinh)
- Strain hardening (1/strain)
- Irradiation hardening (fast fluence)

No explicit consideration of Hydrogen

2. Annealing of strain hardening

3. Annealing of irradiation hardening

Accounts for density of irradiation defects

Cappelaere, Limon, Duguay, Pinte, Le Breton, Bouffieux, Chabretou, Miquet.

Nuclear Technology 177 (2012) 257.

Framatome creep model

Model parameters

Proprietary parameter values for

- Zry-4 (Duplex)
- Zry-2 RX
- M5_{Framatome}

The same parameter values for
Zry-4 and DX (several variants)

Calibration and validation

Fuel Rod Design
in focus

- ~ 100 proprietary creep experiments / material
- irradiated and non-irradiated
- best estimate / conservative prediction required
- underestimation acceptable only for very small creep strains

Relative to 1%
creep strain criterion

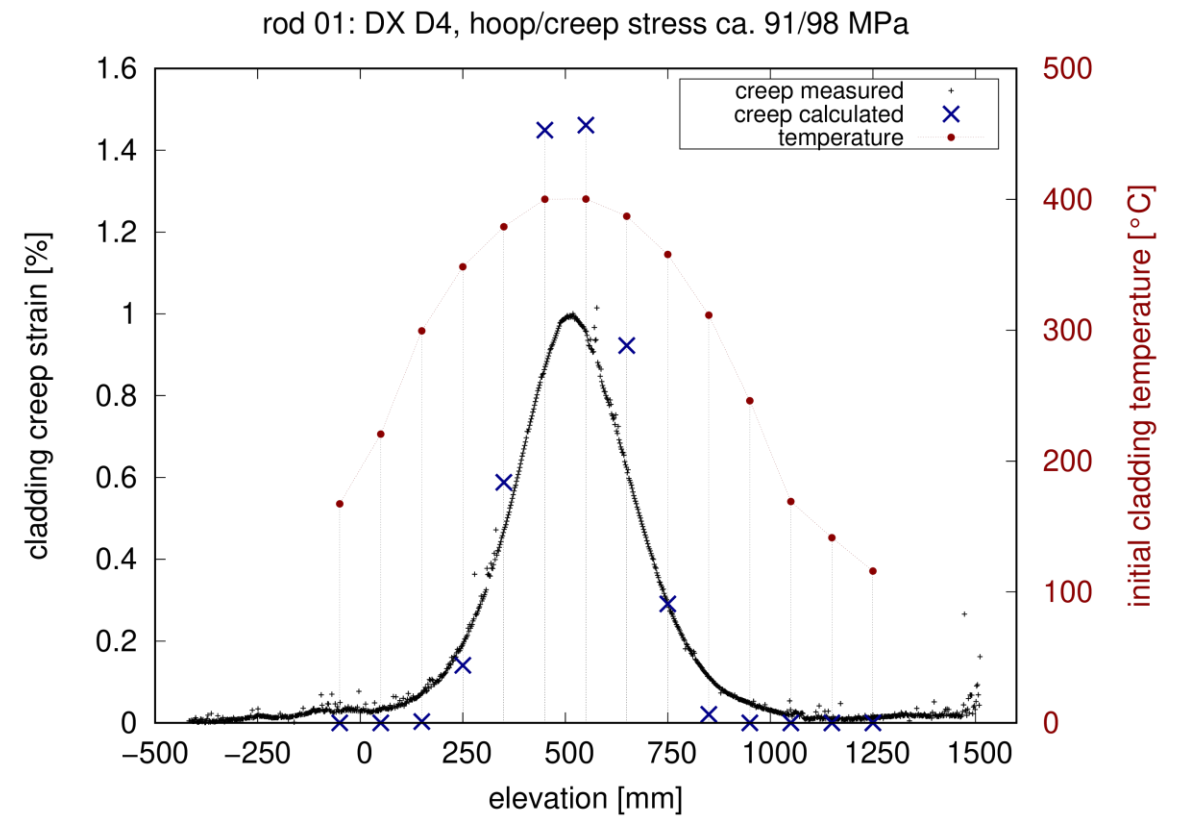
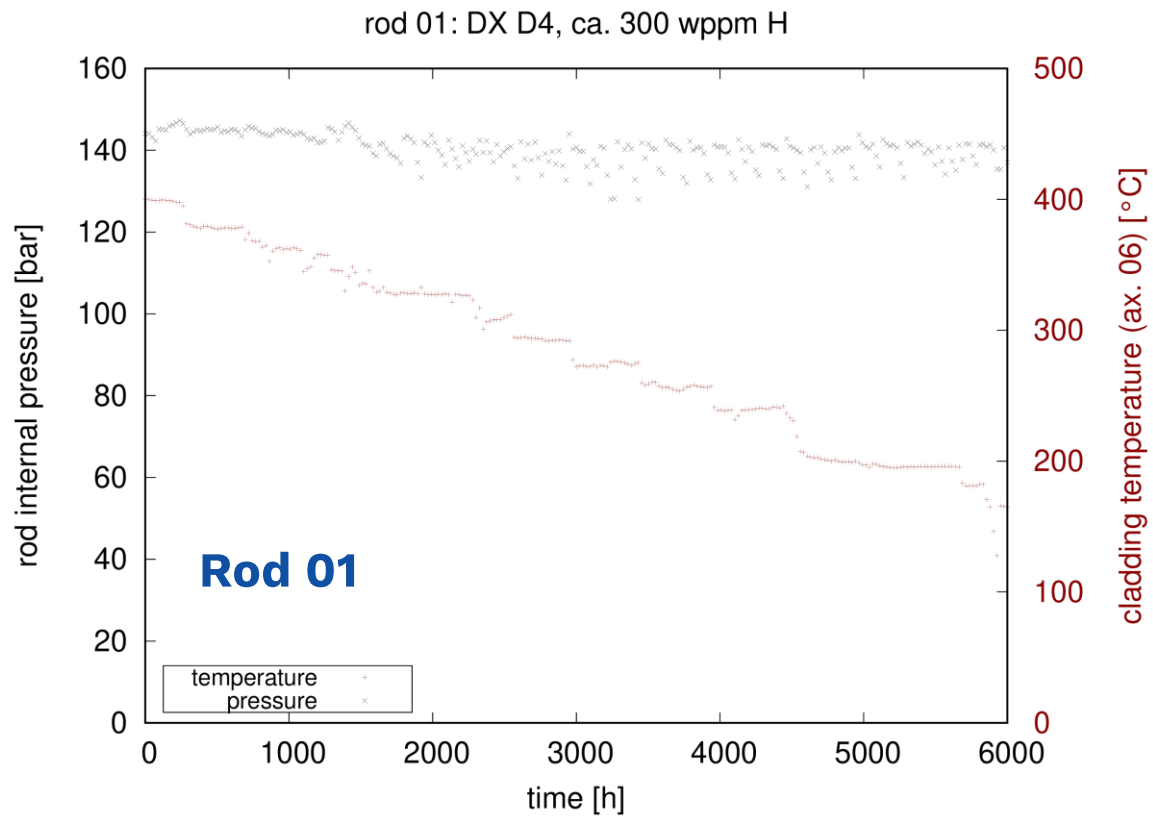
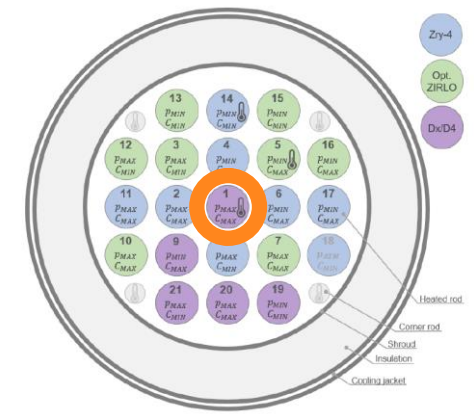
M5_{Framatome} is a trademark or registered trademark of Framatome or its affiliates, in the USA or other countries.

3

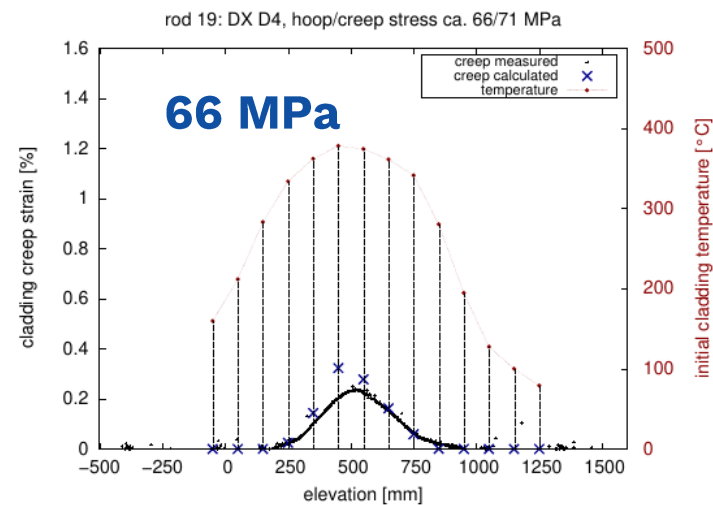
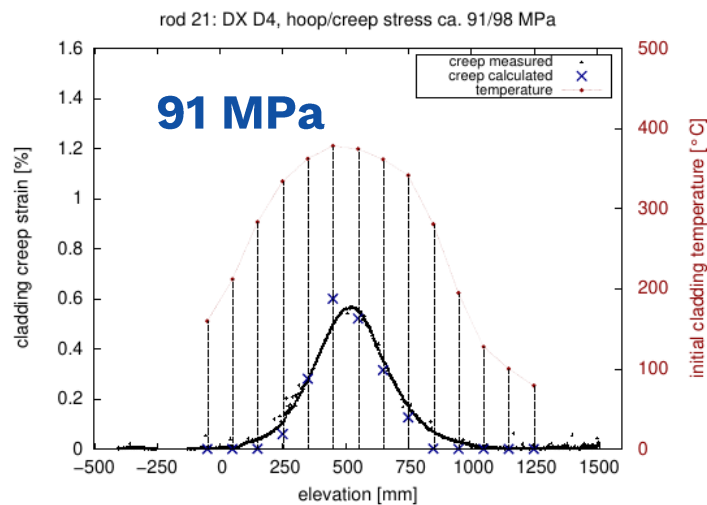
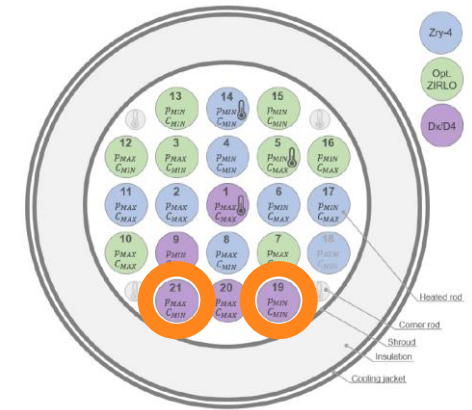
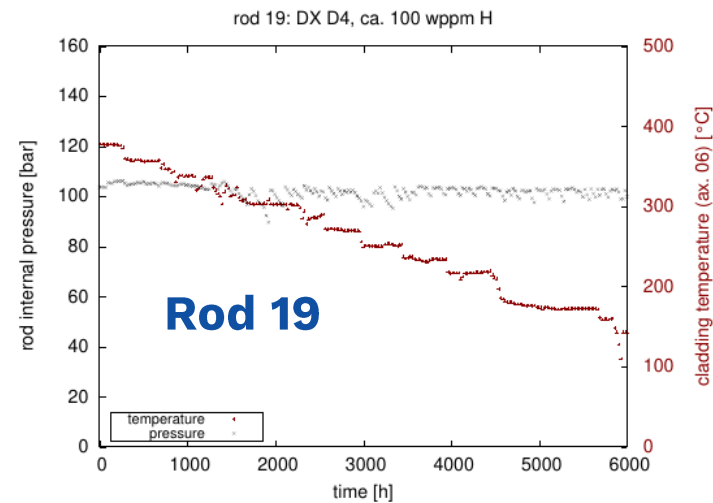
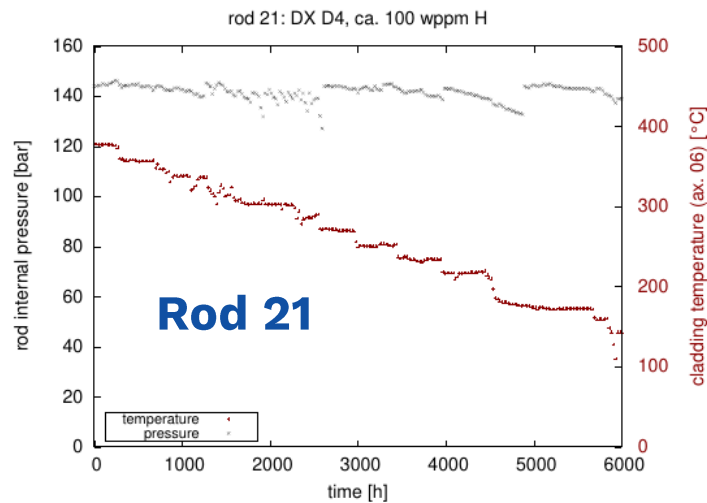
Framatome results

Framatome results

- medium strains: good agreement
- small strains: underestimation (not relevant for FRD)
- large strains: overestimation (conservative)

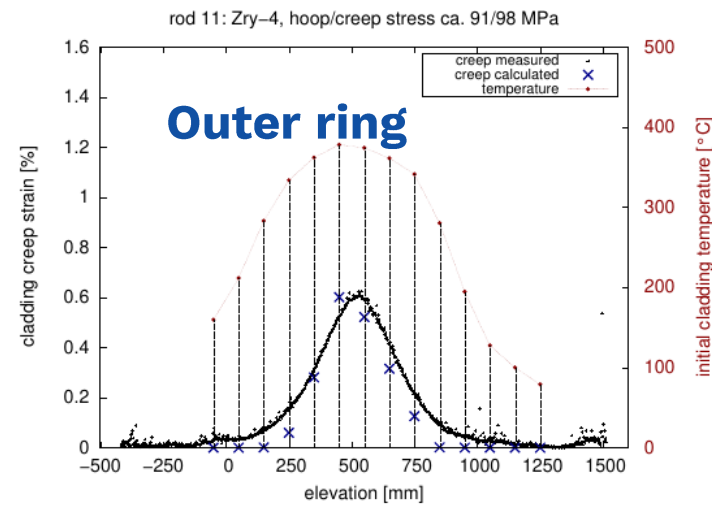
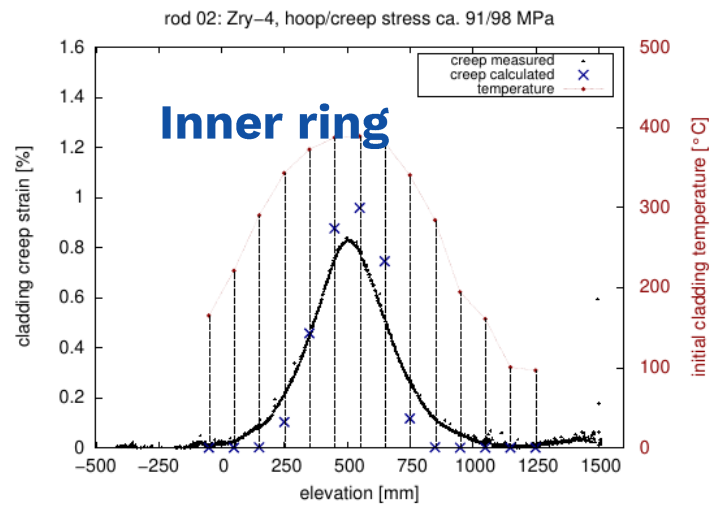
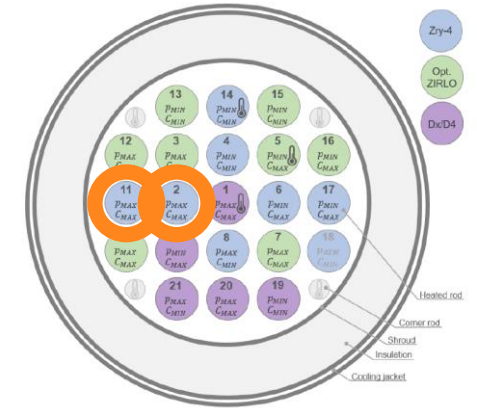
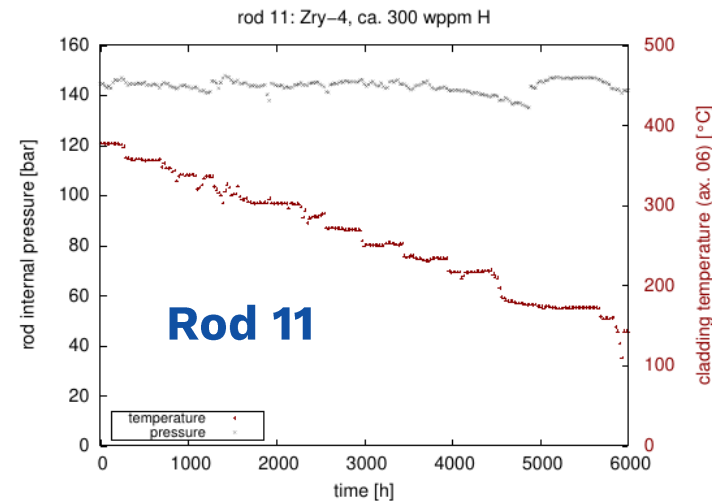
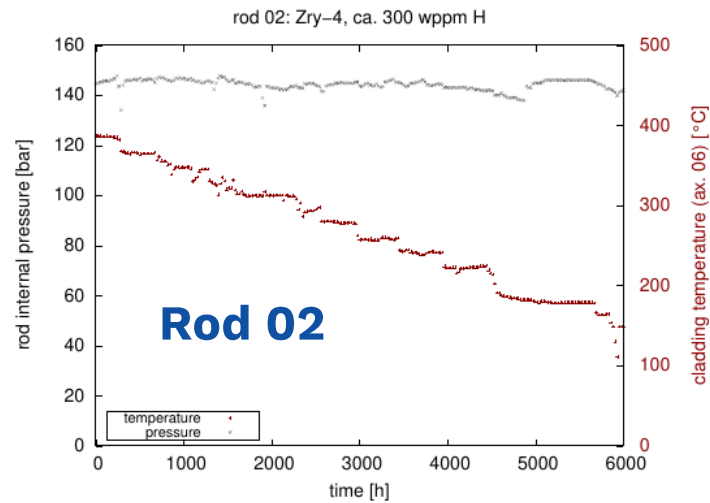


Framatome results



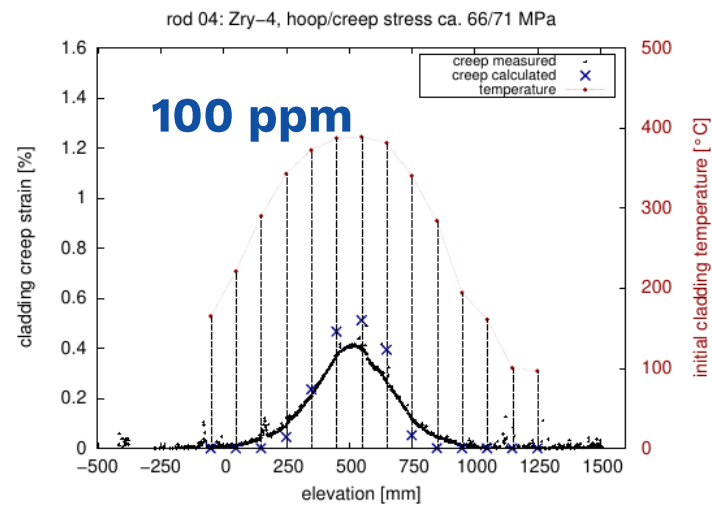
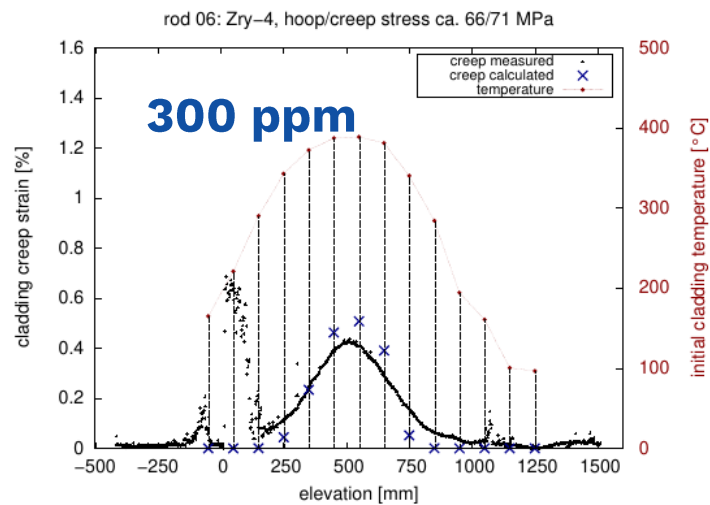
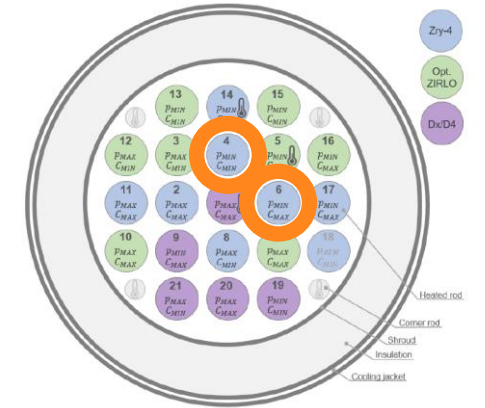
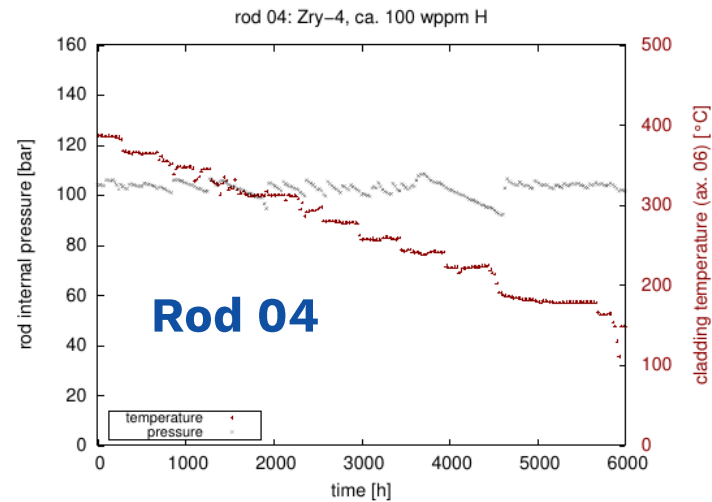
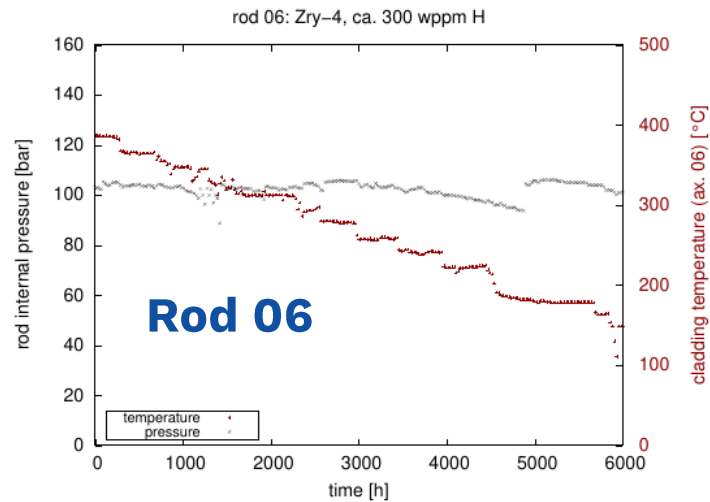
**Effect of stress:
well reproduced**

Framatome results



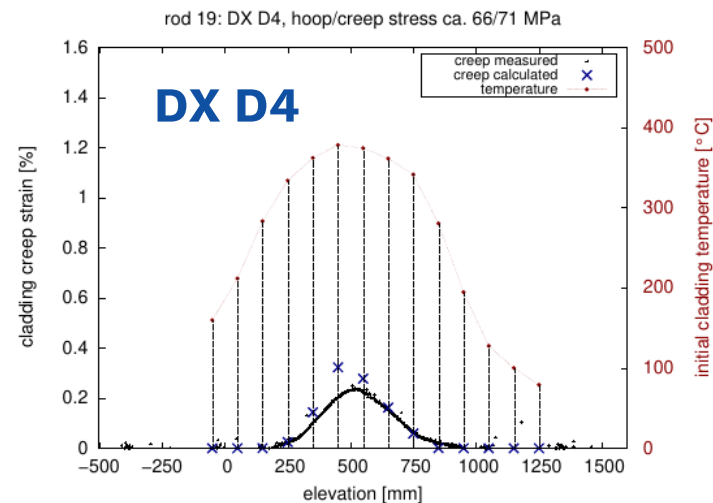
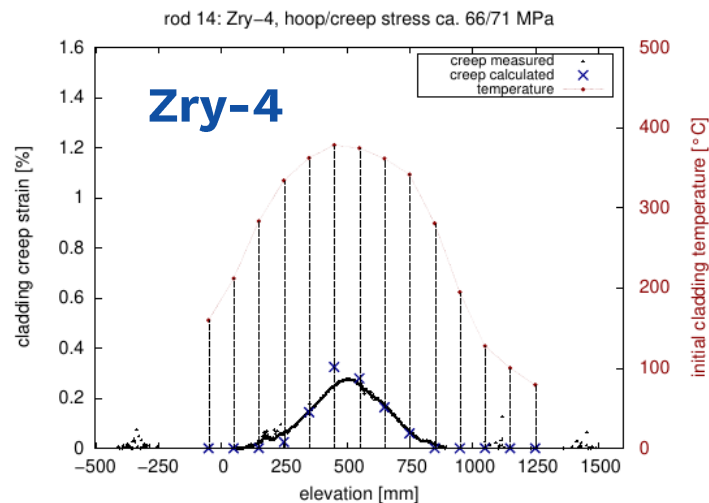
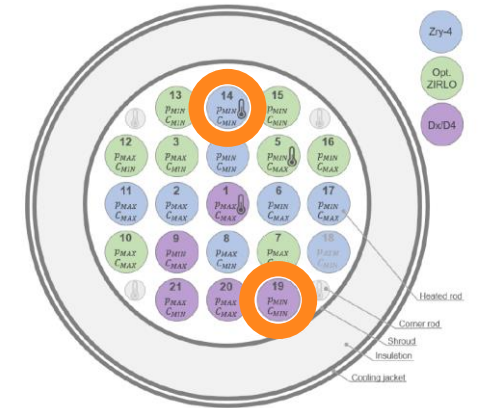
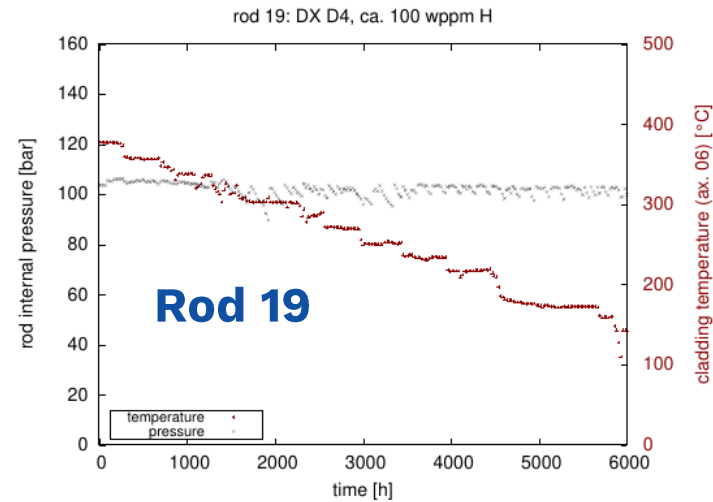
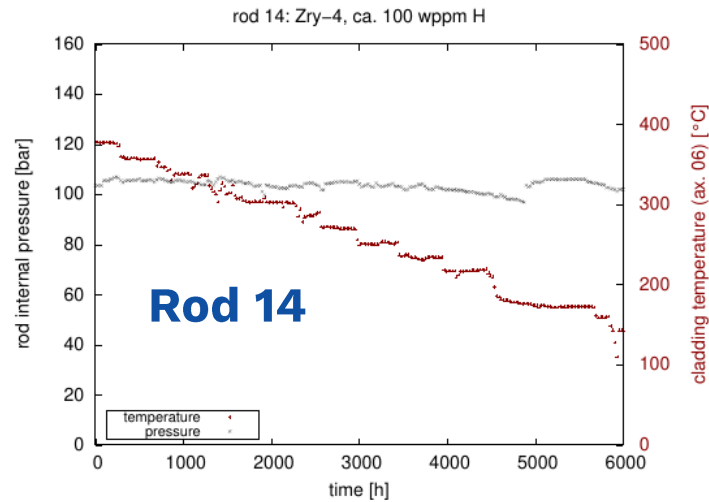
**Effect of temperature:
well reproduced**

Framatome results



**Effect of Hydrogen:
negligible,
not considered**

Framatome results



**Difference Zry-4/DX D4:
negligible,
not considered**

4

Conclusions

Conclusions

- The results of SPIZWURZ benchmark confirm the best estimate / conservative validation of Framatome creep model for dry storage.
- The effects of stress and temperature on creep strain are well reproduced.
- The effects of Hydrogen as well as the difference between Zry-4 and DX D4 are negligible and not considered by the creep model.

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Acknowledgements

Acknowledgements

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- organization and realization of the benchmark
- sharing the experimental data
- support during data evaluation

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Thank
you

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