12th CONFERENCE ON SEVERE ACCIDENTS RESEARCH

May 18-22, 2026 - Madrid, Spain

ERMSAR 2026

ASSESSING THE CAPABILITIES OF MELCOR V2.2 AGAINST THE QUENCH-19 BUNDLE TEST WITH FECRAL CLADDING

F. Rosi[1,2], M. E. Cazado[1], M. Angelucci[2], S. Paci[2], F. Gabrielli[1], V. H. Sánchez-Espinoza[1]

[1]Institute for Neutron Physics and Reactor Technology, Karlsruhe Institute of Technology (KIT), Germany
[2]Department of Civil and Industrial Engineering, University of Pisa (UNIPI), Italy.

1. Introduction & Motivation

- ATF concepts aim to improve reactor safety margins by **reducing hydrogen generation and extending coping** time under off-normal and accident conditions.
- FeCrAl alloys are particularly promising due to their **superior oxidation resistance** in high-temperature steam environments, compared to conventional Zr-based claddings.
- To evaluate the capability of **MELCOR V2.2** to model innovative cladding materials, this study compares simulation results against the **QUENCH-19 bundle test**, conducted at KIT's QUENCH large-scale facility in 2018, focusing on thermal response and hydrogen generation under representative severe accident conditions.

2. FeCrAl Cladding Concept

- Nuclear-grade FeCrAl typically contains ~10-13 wt% Cr and ~5-6 wt% Al. Mo/Y additives enhance oxidation and mechanical performance
- A protective Al_2O_3 layer provides strong oxidation resistance below ~1300°C, above ~1400°C Fe-oxide kinetics become dominant.
- **Main advantages**: reduced steam reaction kinetics and lower hydrogen generation.
- **Main challenges**: higher neutron absorption than Zircaloy, tritium permeability, and UO_2-FeO eutectic interactions at ~ 1335°C.

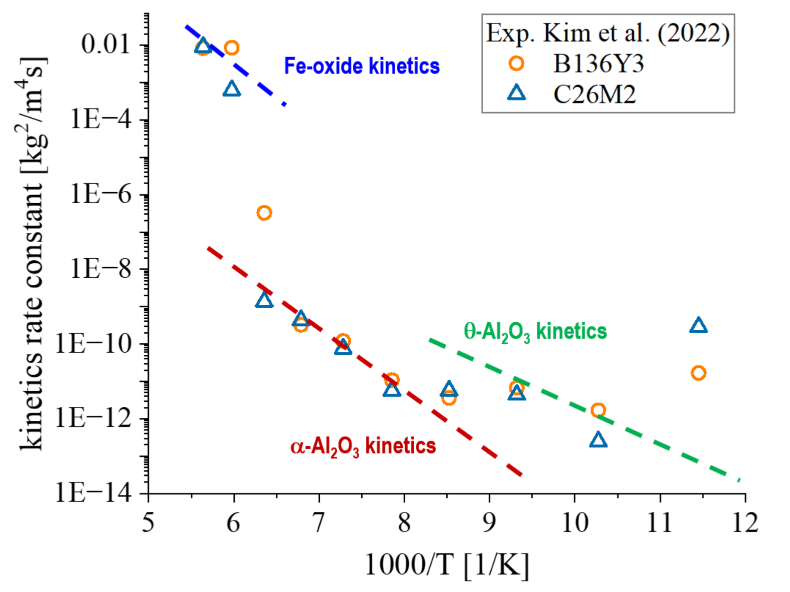


Fig. 1 - Parabolic rate constants of B136Y3 and C26M2 alloys with the parabolic constants of Fe-oxide, α-alumina and θ-alumina [1].

3. QUENCH-19 Bundle Test Modelling with MELCOR

QUENCH-19: first integral ATF bundle test worldwide, performed at KIT in 2018 with FeCrAl (B136Y3) rods.

It assessed the thermal response, oxidation behaviour, and hydrogen release of FeCrAl cladding under severe accident conditions.

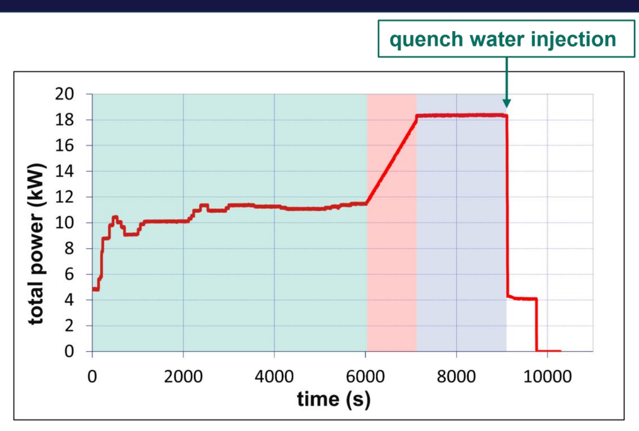


Fig. 2 – QUENCH-19 Electric power [2]

Key experimental findings

✓ No early temperature runaway relative to ZIRLO reference exp (QUENCH-15).
✓ Max. temperature ~200 K lower in the pre-oxidation phase.
✓ Strong H_2 reduction: 9.2 g vs 47.6 g (QUENCH-15).

MELCOR Modelling

CVH Nodalization

- **Test section** divided in **9 Control Volumes** (CVs).
- Additional CVs included for lower plenum, off-gas collector, argon insulation and auxiliary regions.

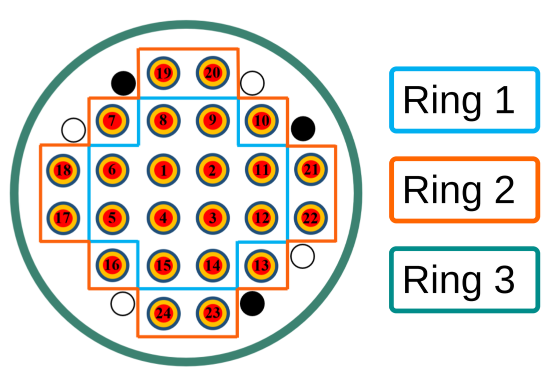


Fig. 3 – Radial Nodalization

COR Radial Nodalization

- Test section divided in **three radial rings**.
- Ring 1 and 2 represent the heated region: 12 rods each.
- Ring 3 contains 7 corner rods (unheated) and shroud.

Core Components

- **B136Y3** material defined as the oxidizable user material. Properties obtained from literature and KIT data [3, 4] Claddings, corner rods, shroud, and spacer grids are represented with this user-defined material.
- **B136Y3OX oxide** material represented using MELCOR default properties.
- **W**, **Mo**, and **Cu** (heater/electrode) properties defined through the MP package.
- **ZrO_2 pellets** modelled via UO_2 as a placeholder material with ZrO_2 properties.

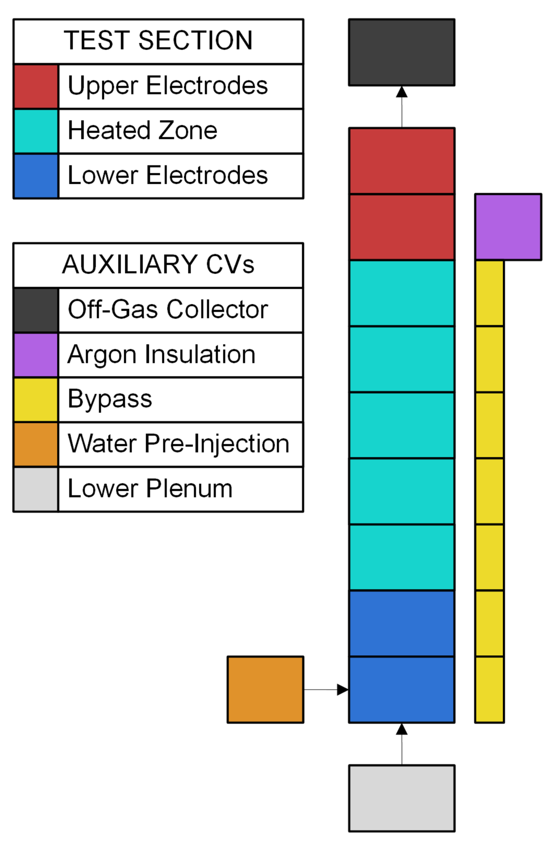


Fig. 4 – CVH Nodalization

FeCrAl Oxidation Model

- Oxidation implemented via a user-defined **GOX model**.
- Ox. kinetics adapted from KIT separate-effect tests (SETs).
- Transition from α-Al_2O_3 to Fe-oxide kinetics at 1400°C.

4. Simulation Results

A. Cladding Temperature Evolution

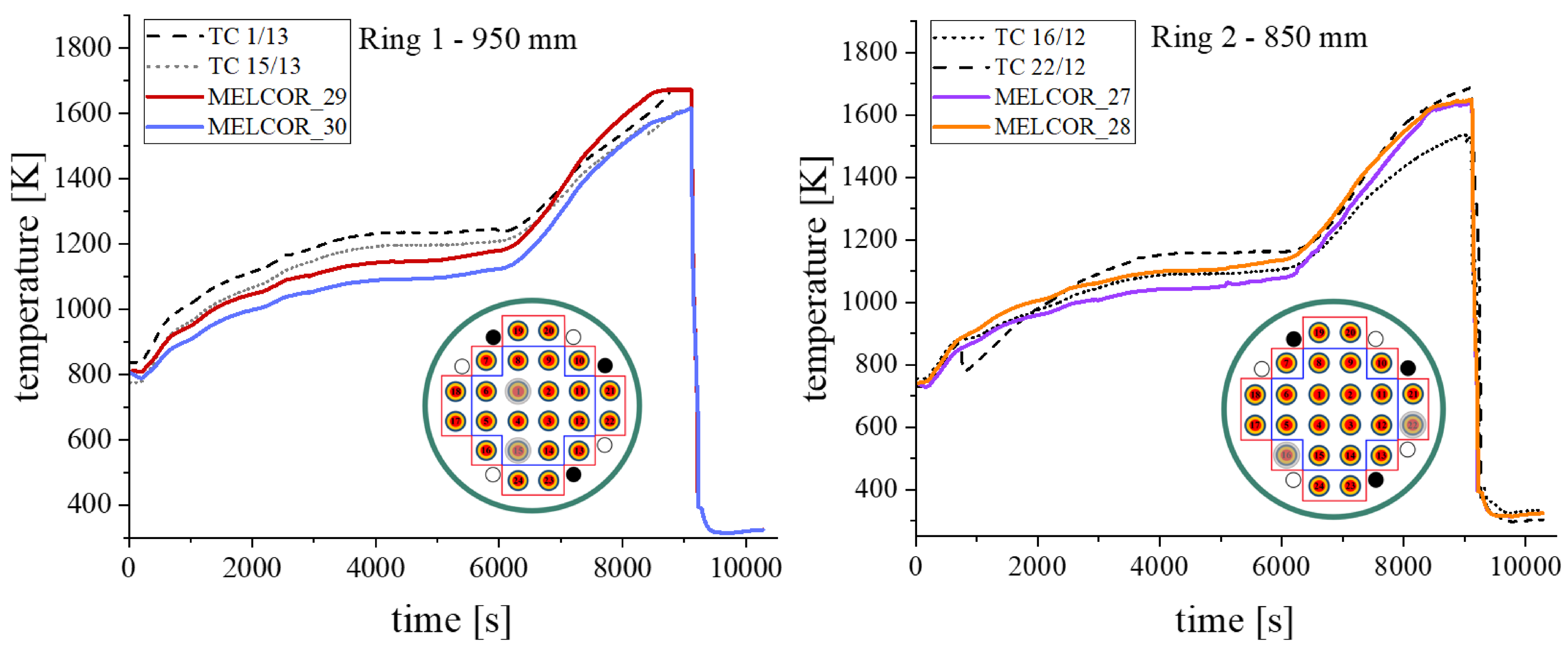
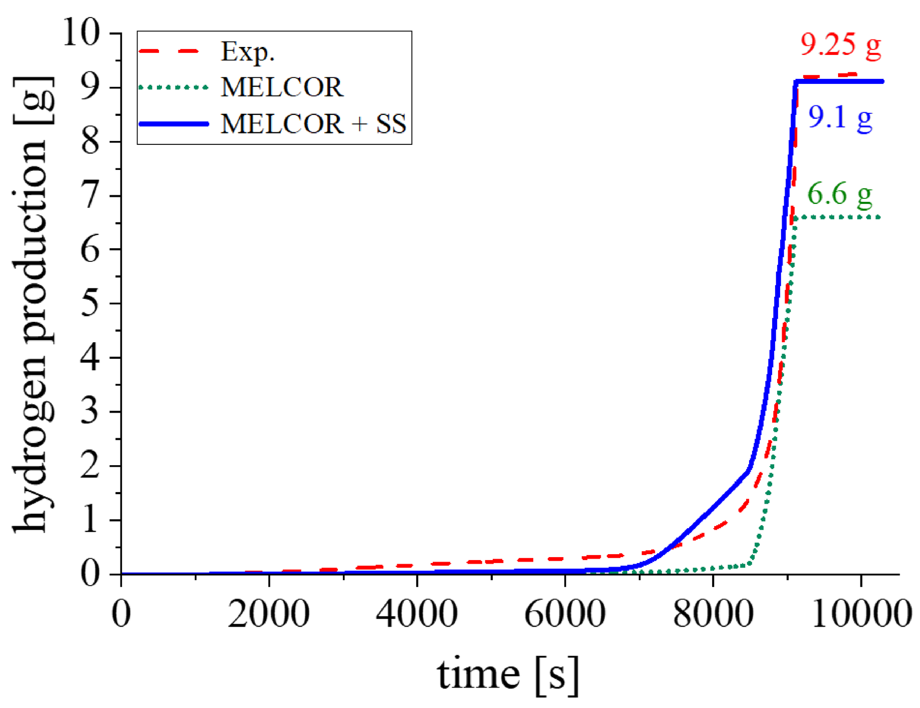


Fig. 5 – Cladding temperature comparison between the experimental data [2] and simulated results at 950 mm elevation in Ring 1 (left) and at 850 mm in Ring 2 (right). The dotted and dashed curves correspond to the experimental thermocouple data: the associated rod positions are highlighted in grey in the test cross-sections.

B. Hydrogen Generation



- It is estimated that ~2 g of the experimental H_2 production originates from the **oxidation of stainless-steel thermocouple sheaths**, accounting for ~ 22% of the total measured H_2.
- As these components are not modelled explicitly in MELCOR, their contribution was estimated separately using simulated temperatures and the area of the exposed sheaths.

Fig. 6 – Cumulative hydrogen production comparison between the experimental data [2] and MELCOR results. The dotted line shows the MELCOR simulation that considers only the H_2 generated by the FeCrAl material. In contrast, the solid blue line includes the contribution of the oxidation of the stainless steel thermocouple sheaths.

5. Conclusions

- A MELCOR input deck for QUENCH-19 was developed based on KIT report specifications and FeCrAl oxidation data obtained from KIT SETs.
- Despite some deviations, mainly attributed to core nodalization constraints, **MELCOR shows good agreement with QUENCH-19 data** for temperature evolution and cumulative hydrogen generation.
- **FeCrAl** cladding **significantly mitigates hydrogen generation below ~1400°C** compared with equivalent tests using Zr-based alloys.
- Oxidation of stainless-steel thermocouple sheaths can provide a relevant additional hydrogen source in ATF experiments and should be considered in the interpretation of the results.

Acknowledgements

SEAKNOT

The work has been performed in the framework of the mobility program of the EU SEAKNOT project, which has received funding under the Grant agreement No. 101060327. The content of this work reflects only the authors' view. The European Commission is not responsible for any use that may be made of the information it contains.

References

[1] C. Kim, et al., "Oxidation mechanism and kinetics of nuclear-grade FeCrAl alloys in the temperature range of 500-1500°C in steam," *Journal of Nuclear Materials*, vol. 564, p. 153696, 2022.

[2] J. Stuckert, et al., "Results of the bundle test QUENCH-19 with FeCrAl claddings," *KIT Scientific Report NUSAFE-3575*, 2022.

[3] P. Aragon, et al., "Modelling FeCrAl cladding thermo-mechanical performance. Part I: Steady-state conditions," *Progress in Nuclear Energy*, vol. 153, 2022.

[4] K.G. Field, et al., "Handbook on the Material Properties of FeCrAl Alloys for Nuclear Power Production Applications (FY18 Version: Revision 1)," ORNL, 20218.

Reactor Physics and Dynamic

Contact: mauricio.cazado@kit.edu