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Evaluation of a BDBA Quench Sequence in a Generic iPWR with Natural Circulation: Application of the QUENCH-06 Experiment.

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Introduction

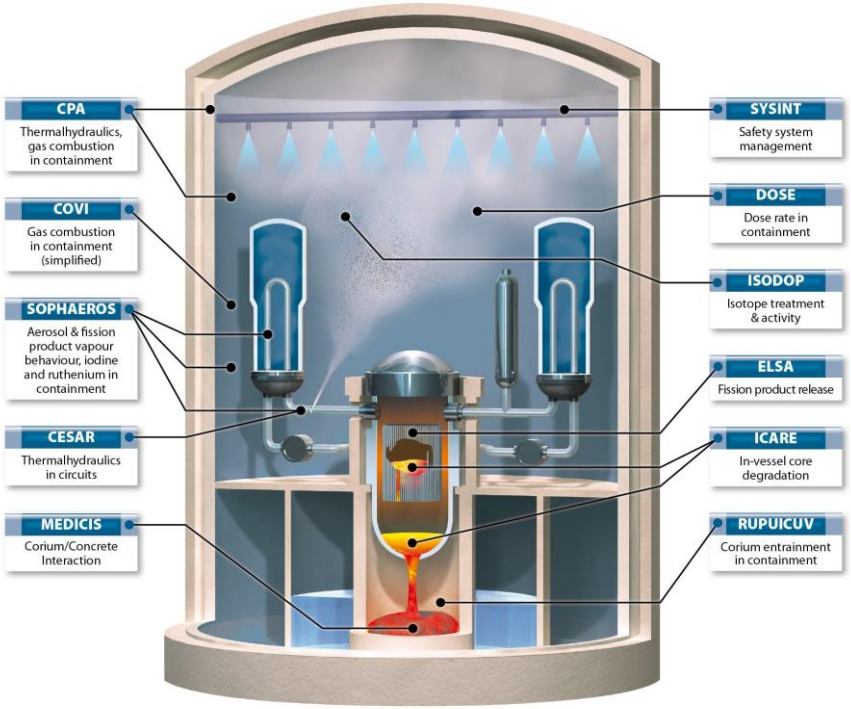
- SMRs are a promising innovation in nuclear energy for clean, reliable, and cost-effective energy solutions.
- These advanced reactors designed are smaller than traditional NPPs with enhanced safety.
- Understanding hydrogen generation during BDBA is critical for assessing safety margins in SMRs.
- The QUENCH experiments are to investigate the hydrogen generation as results of water or steam injection in an uncovered core of a LWR: QUENCH-06 used water for cooling down the bundle.

Goal: Evaluate the applicability of QUENCH-06 data to predict the H_2 generation in a generic SMR during a quench sequence.

Introduction

ASTEC - Accident Source Term Evaluation Code developed by the French Institute for Radioprotection and Nuclear Safety (IRSN).

The code simulates the complete accident sequence in NPPs, from the initial event to the potential release of radioactive materials

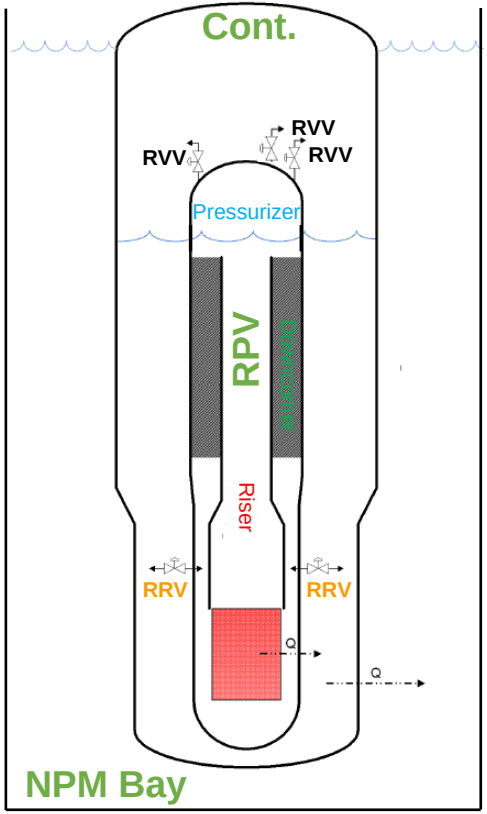


iPWR Design – General description

- Power: 45 MWe (160 MWt)
- Natural-circulation pressurized water reactor.
- Integrated reactor: core, pressurizer, helical-tube steam generators (HTSGs), Hot leg riser and Downcomer in RPV.
- RPV surrounded by Steel containment vessel immerse in a water pool.

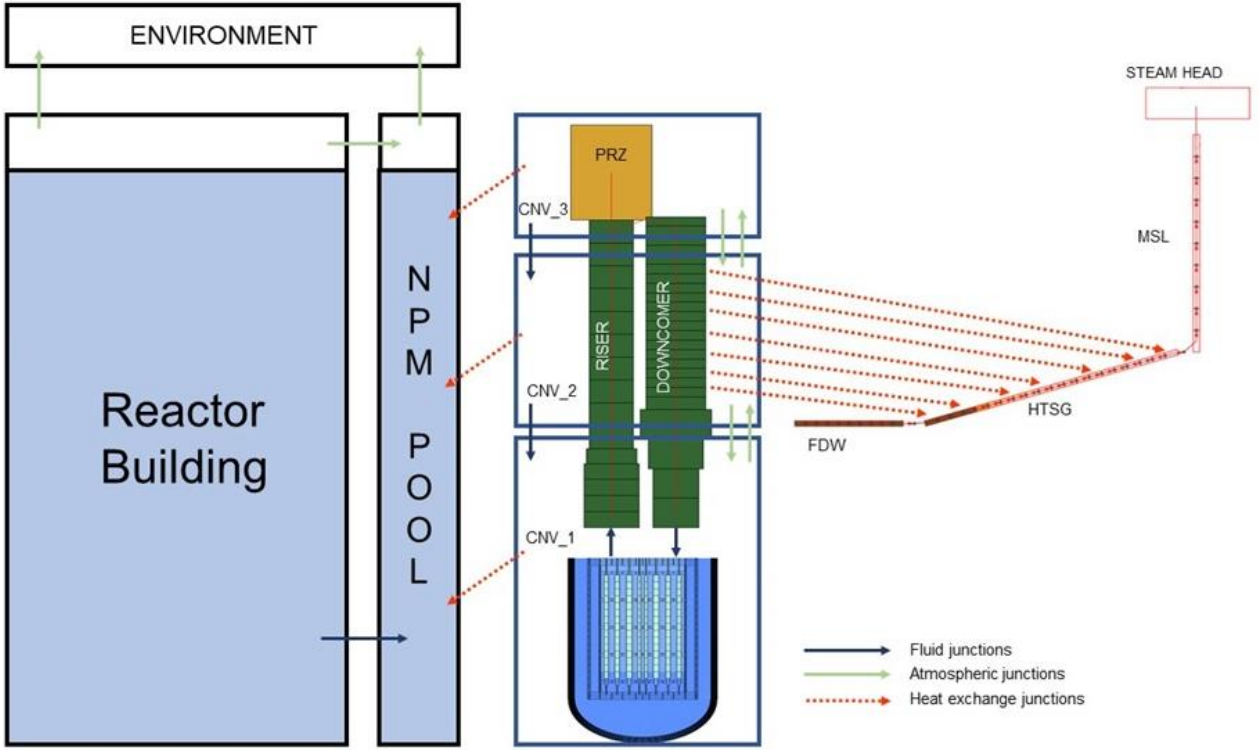
Safety systems:

- Emergency Core Cooling Systems (ECCS): Primary coolant is collected at the Cont. and recirculation valves opens to generate a flow path.
- Containment Heat Removal System (CHRS): transfer energy to the pool by conduction and convection modes.



iPWR Model Nodalization

ASTEC v3.1 is employed to assess selected sequence in the generic SMR.



Quench Scenario Selected

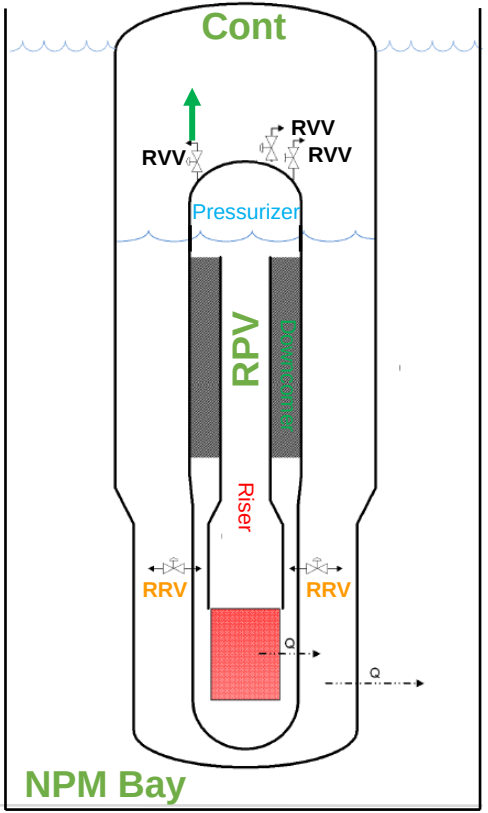
2. SA Description

Spurious opening of 1 RVV.

- Loss AC (Feedwater, CVCS)
- ECCS activation ($DP_{Cont–RPV}$ < 6.9 MPa & Cont. level > 5.8 m)
- 2 RVVs available
- 2 RRVs not activated when the ECCS signal is triggered.
- After certain cladding temperature is reached the RRVs open: Tclad = 1973 [K] in the 3rd channel.

Initial Conditions

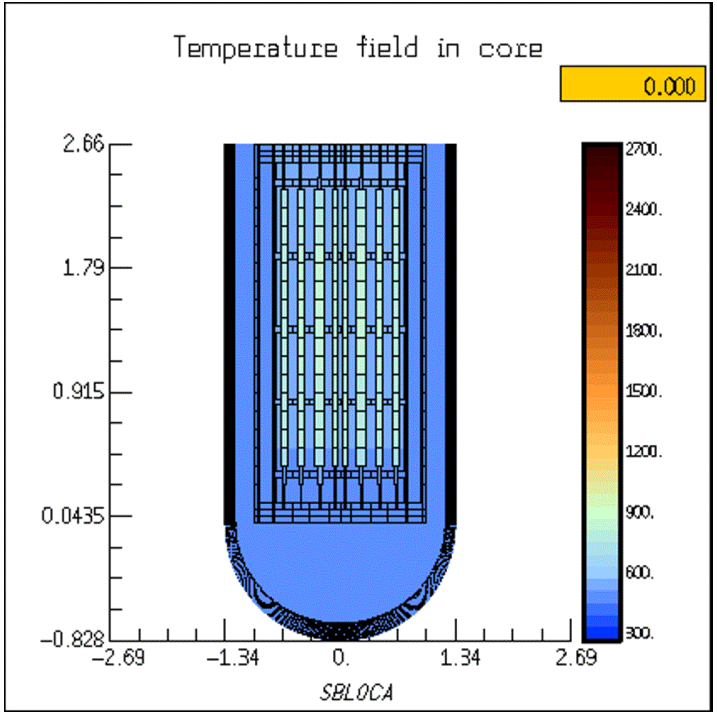
Parameter	value
Core Power [MW]	160.00
Feedwater Temperature [K]	422.0
Feedwater Pressure [MPa]	3.8
Average Core Temperature [K]	560.0
Burnup [MWd/kgU]	60.0
Containment Temperature [K]	320.0
Pool Temperature [K]	320.0
Pool water level [m]	16.8



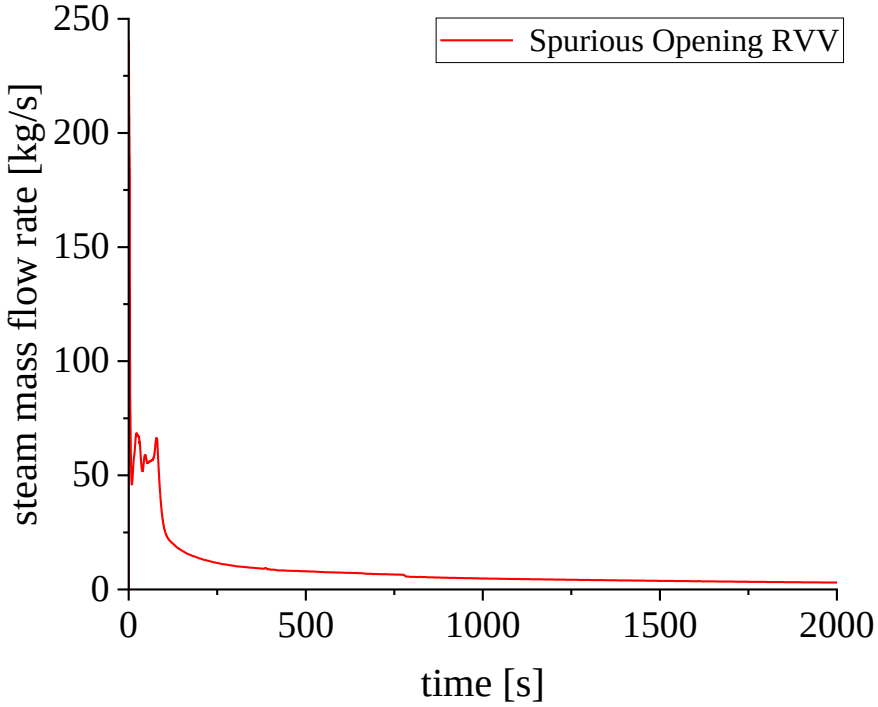
Results: Quench Scenario

Scenario Progression

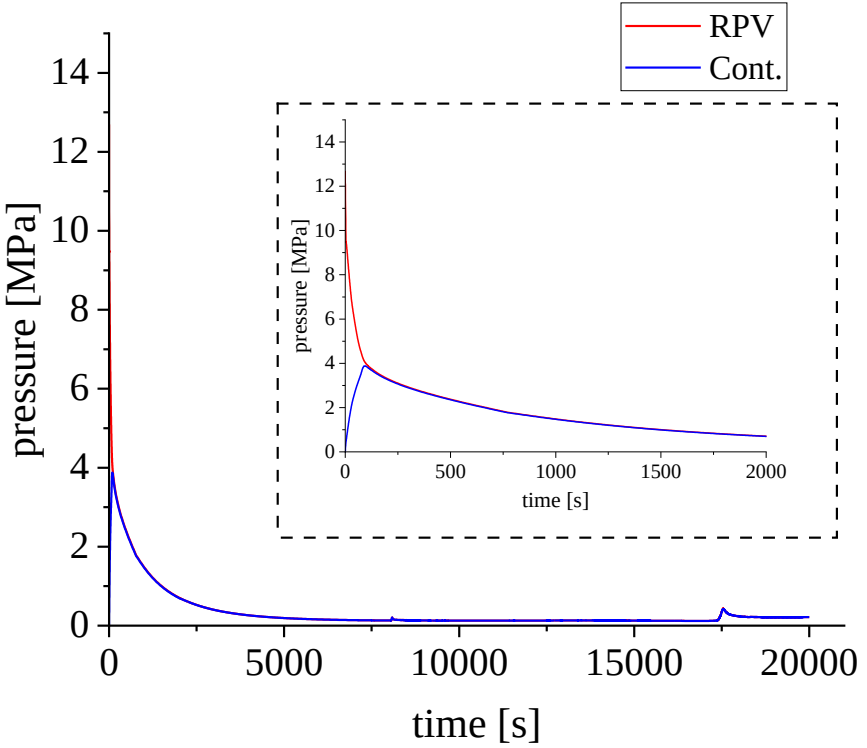
key parameters	ASTEC
SCRAM time [s]	3.5
ECCS actuation time [s]	2032
Max. Press in Cont [MPa]	3.9
Max. liq. Level in Cont. [m]	8.6
Start of core uncovering [s]	~11400
Quenching Signal	17337
Start reflooding	17372
H2 onset time [s]	15102
Start of FPs release from fuel pellets [s]	16608
Total H_2 mass produced in the Vessel [kg]	7.7
Final H_2 mass in Cont. [kg]	7.1
Final aerosols mass in Cont. [kg]	6.2



Results: Quench Scenario

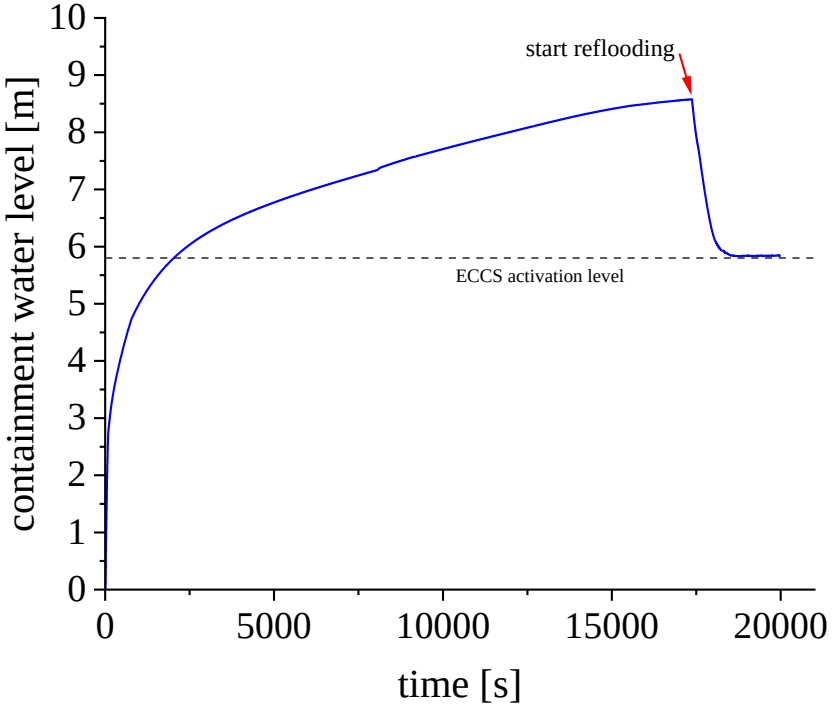


Steam mass flow rate evolution through the RVV during the scenario

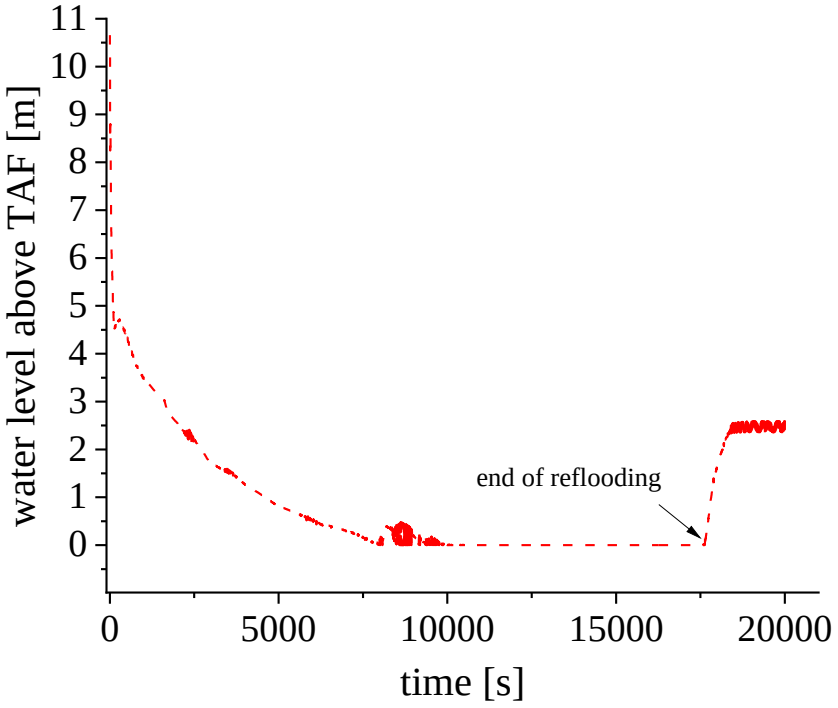


RPV and containment vessel pressure evolution

Results: Quench Scenario

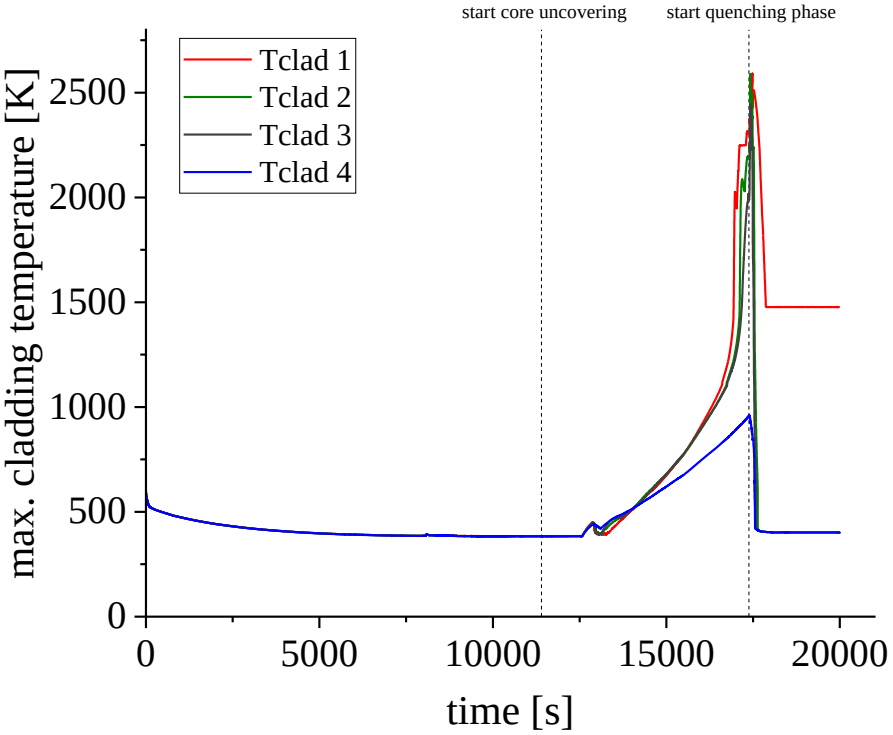


Evolution in time of water level in the containment for the BDBA case proposed.

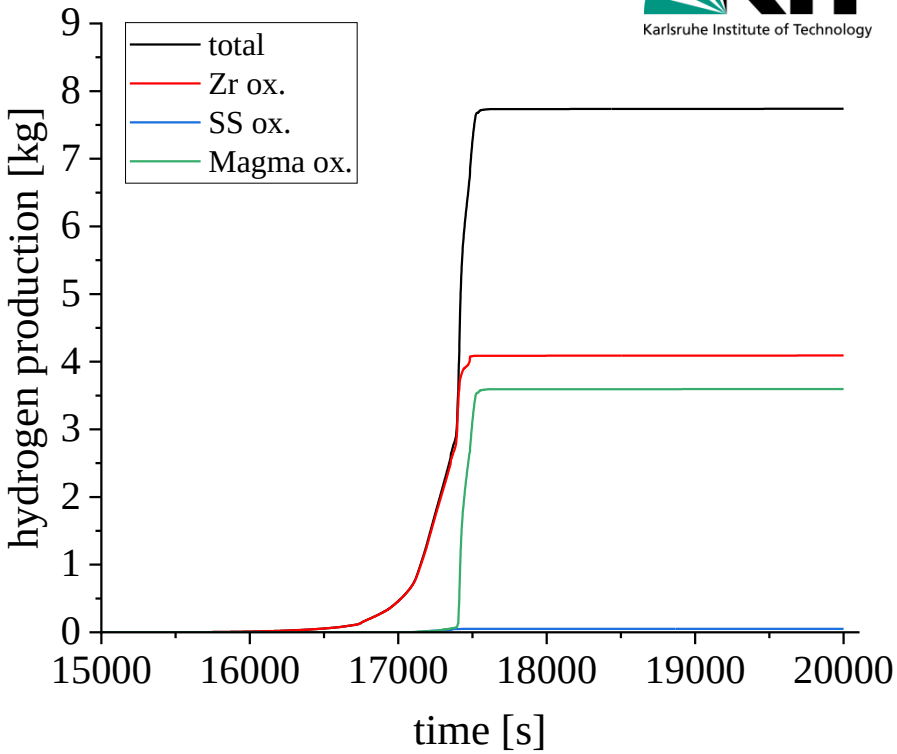


Evolution in time of water level above TAF in the Vessel for the BDBA case proposed.

Results: Quench Scenario

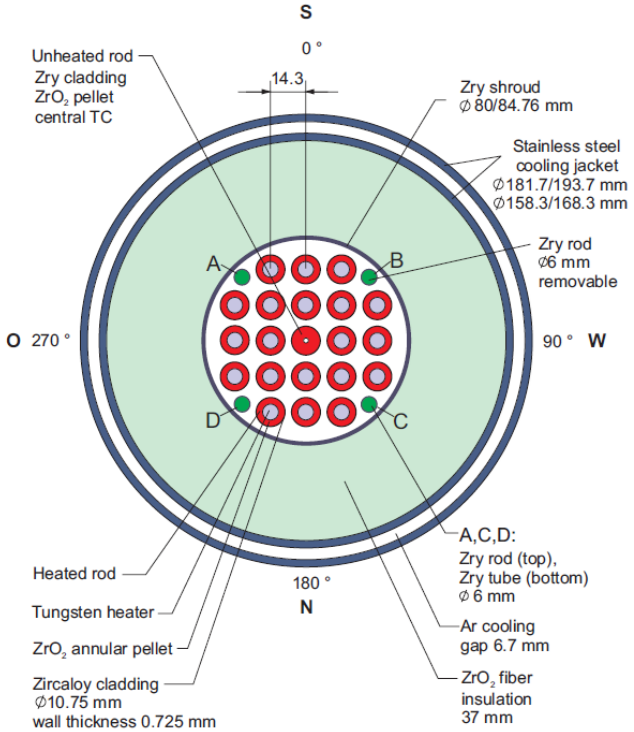


Maximum temperatura evolution for different channel during the selected BDBA scenario.

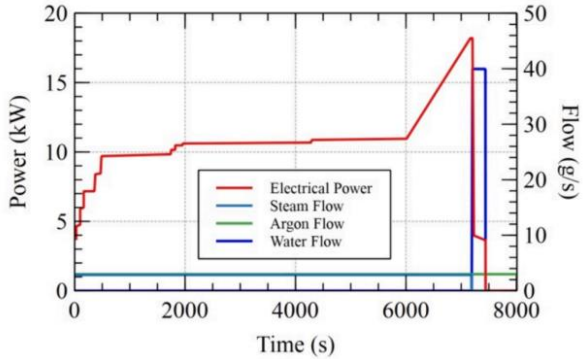


Total hydrogen generation in the RPV with different oxidation contributions during the selected BDBA scenario.

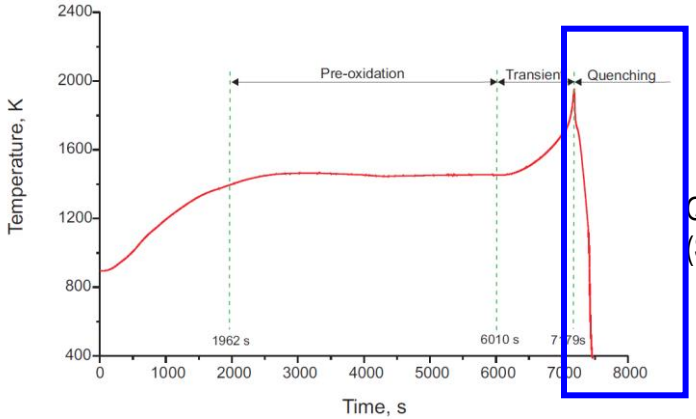
QUENCH-06: How to apply the exp. results?



QUENCH-06; Test bundle; TC instrumentation and rod designation (Sepold et al. 2004)

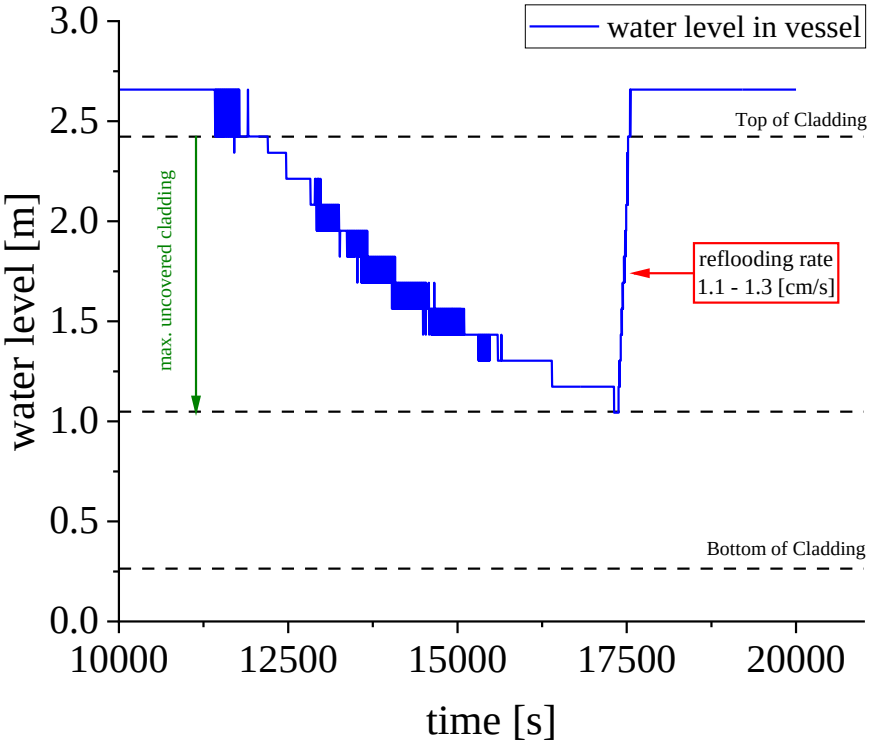


QUENCH-06 electrical power and boundary conditions (Sanchez-Mora et al. 2024)



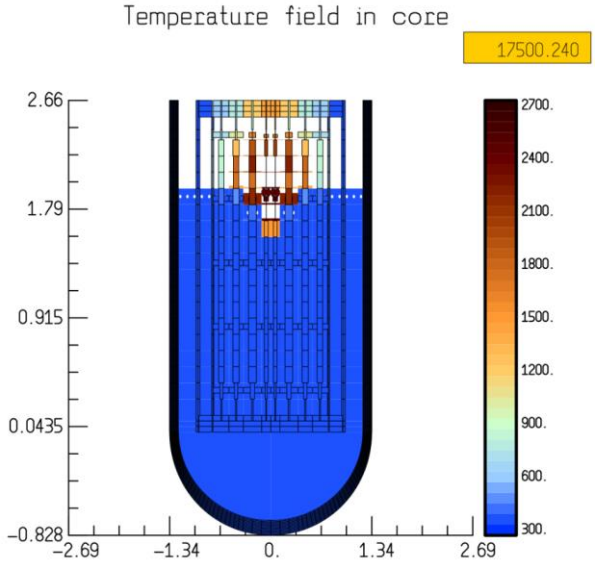
QUENCH-06; Test phases (Sepold et al. 2004)

Results: Exp. vs Sim.



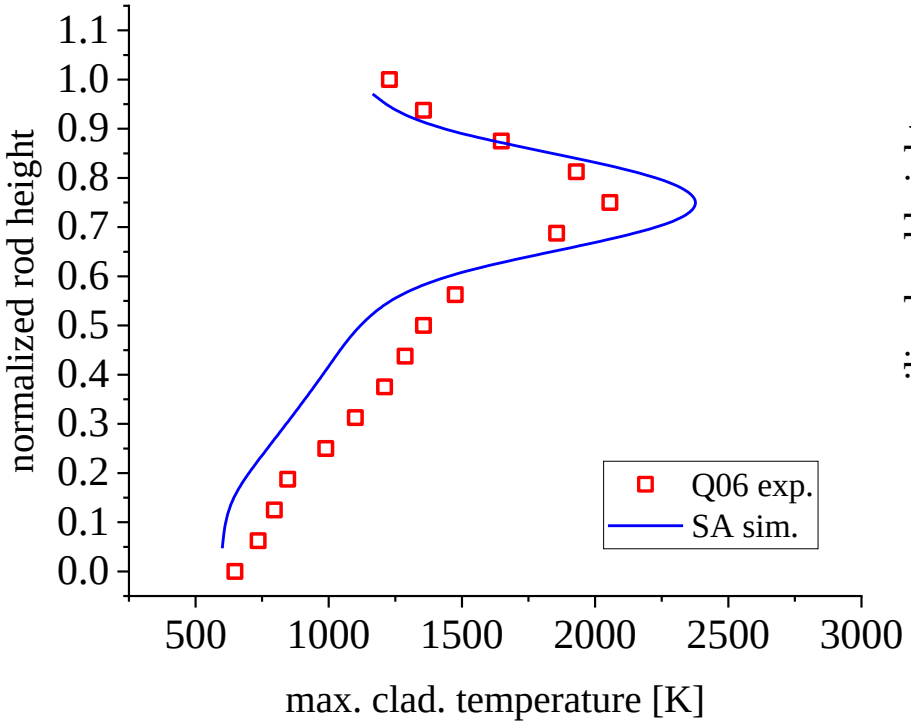
Water level evolution in the core during the selected BDBA scenario

Channel 3: Similar temperatures and less magma formation

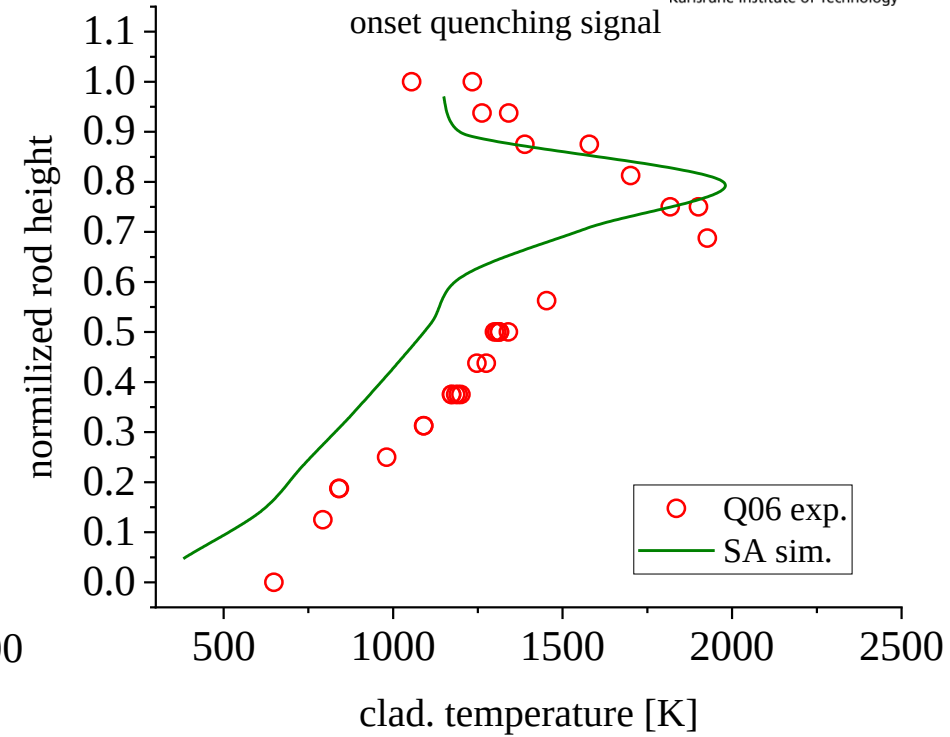


Exp. reflooding rate: ~1.4 [cm/s]

Results: Exp. vs Sim.

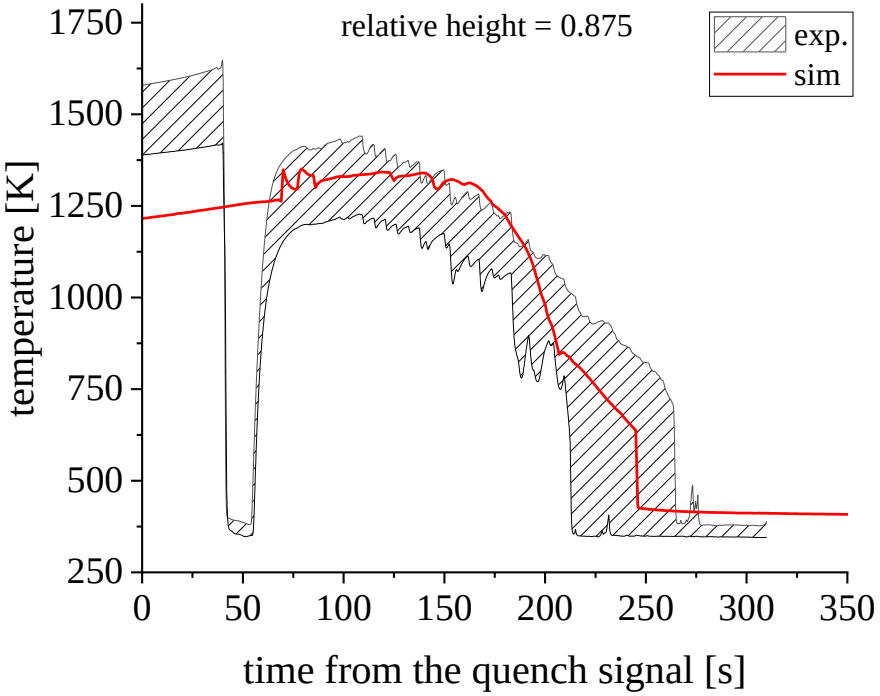


Maximum temperature profile comparison between the simulation (Claddings in channel 3) and Q06 exp.

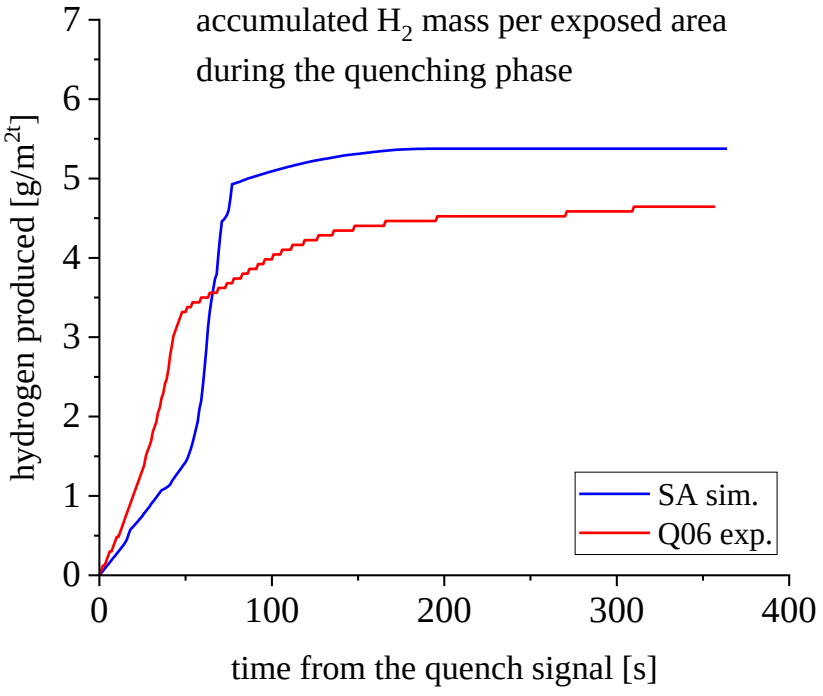


Temperatura profile comparison between the simulation (Claddings in channel 3) and Q06 exp. on the onset of the quenching signal

Results: Exp. vs Sim.



Temperature evoluation comparison between the simulation (Claddings in channel 3) and the experiment for a correspoing relative height of 0.875



Hydrogen generation during the quenching pase for the experiment and simulation (Claddings in channel 3)

Conclusions

- A Quench scenario in a generic natural circulation iPWR was evaluated during this work showing that the ASTEC code can adequately simulate the Thermal-hydraulics and Core Degradation phenomena.
- In this analysis, the quenching phase results from the QUENCH-06 experiment showed reasonable agreement with the simulations for the hydrogen generation in the channel 3 of the core discretization in a generic SMR design during a BDBA. Some expected deviations are observed.
- These preliminary comparisons show that the QUENCH tests provide highly valuable experimental data for SMRs' safety assessments.
- Further experimental validation and simulation assessments are needed to address diverse accident scenarios and enhance predictive capabilities.

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Thank you for your attention