Preliminary results of PARAMETER SF2 post-test calculation with ATHLET-CD

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13th Meeting, Budapest, Hungary, March 3 – 6, 2008

Parameter SF2 post-test calculation with ATHLET-CD

- Input model, boundary conditions
- Input parameter
- Calculation results with standard modelling of entrainment and interfacial friction
- Quenching with earlier onset of entrainment and increased interfacial friction
- Conclusion

- Acknowledgement
  - The development and validation of ATHLET-CD are sponsored by the German Federal Ministry of Economics and Technology BMWi

Cladding oxidation model

Rate constant ($g^2/cm^4/s$)

$$XP_i = A_i \cdot \exp(-E_i / T)$$

Oxidation limitation

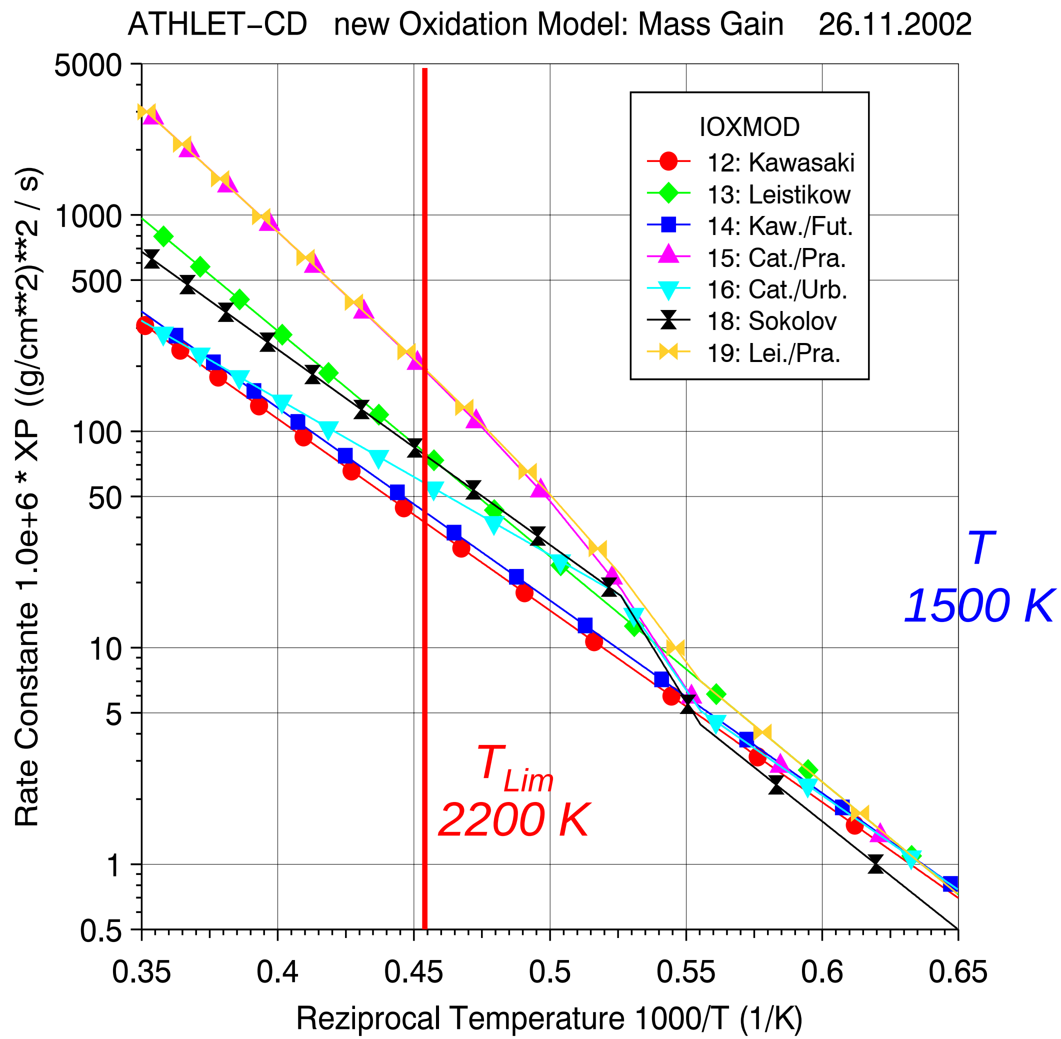
$$R_i = XP_i \cdot g_{Limit}$$

$$T \leq T_{Lim}$$

Mass gain (g/cm^2)

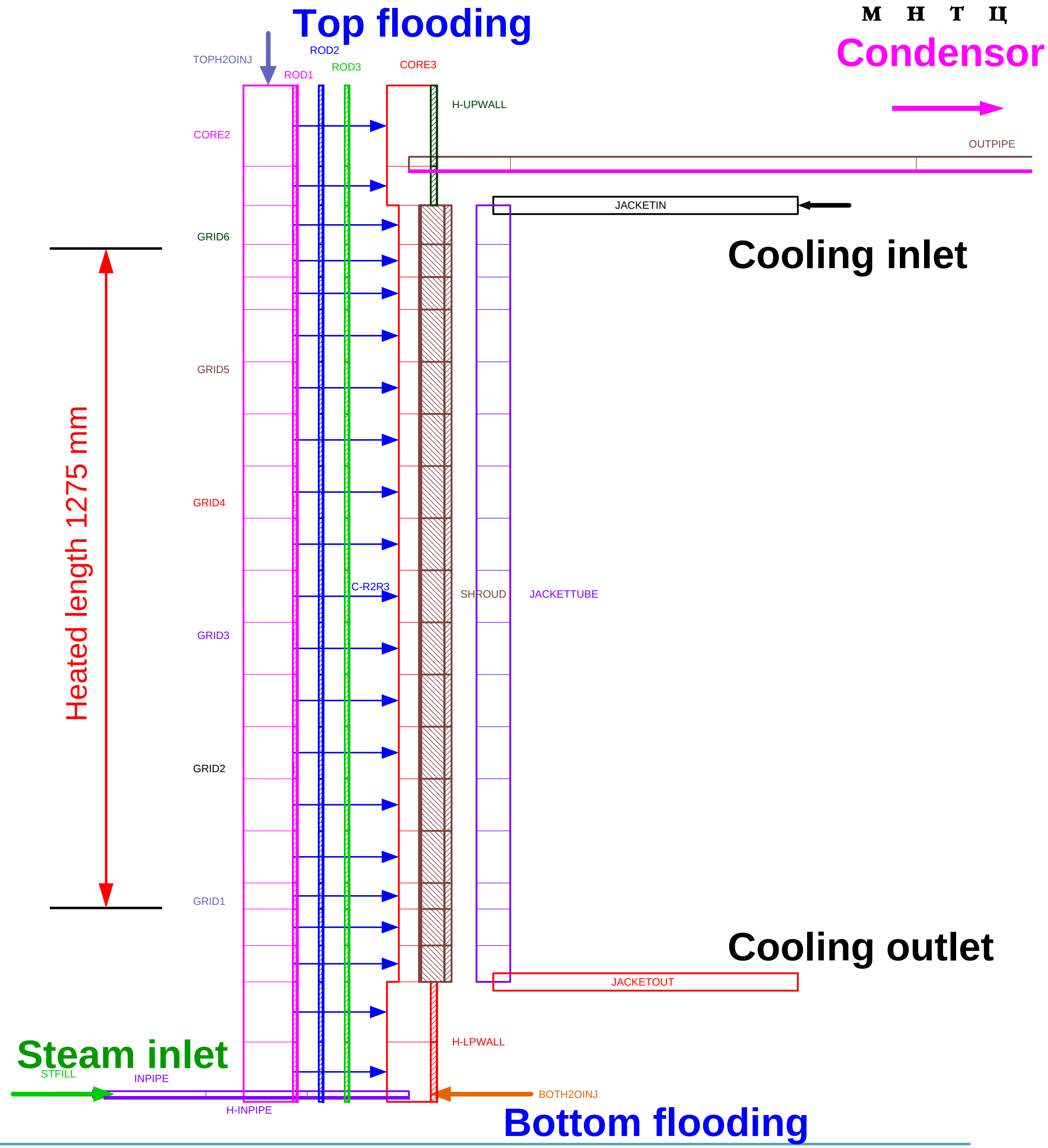
$$\frac{dm''}{dt} = \frac{R_i}{m''}$$

Used correlation IOXMOD = 19
Leistikow / Prater-Courtright
(Sokolov: IOXMOD = 18)



Parameter SF2 input model

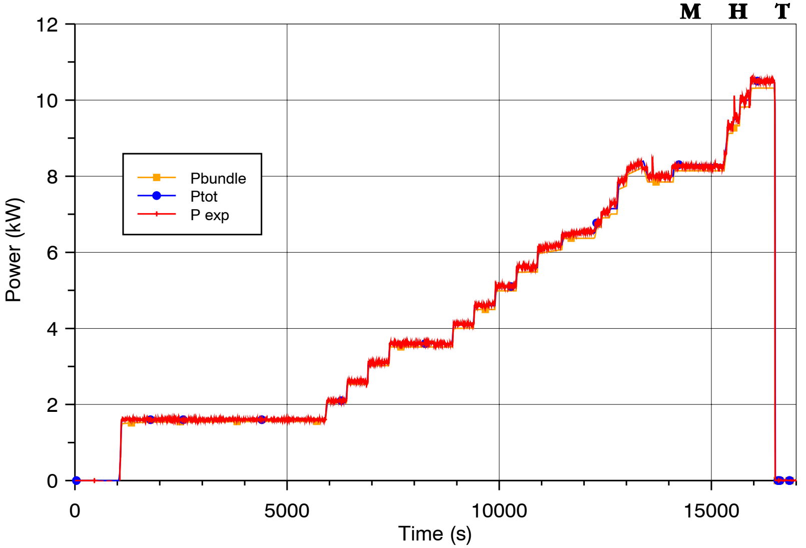
- Flow simulation
  - In-pipe
  - Bundle 85.7%
  - Bypass 14.3%
  - Off-pipe
  - Cooling
- Structures
  - Rods 1/6/12
  - Grids
  - Shroud
  - Insulation
  - Cooling



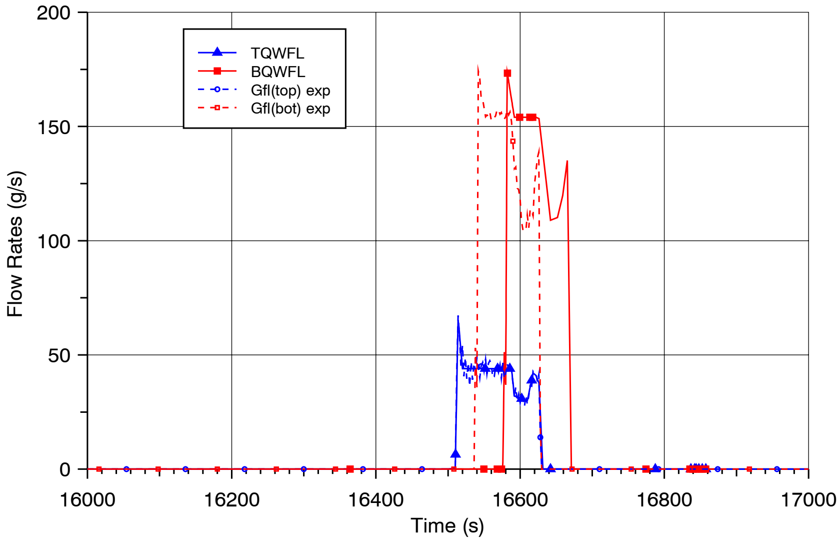
Top part	305 mm
Heated length	1275 mm
Bottom part	370 mm

Boundary conditions

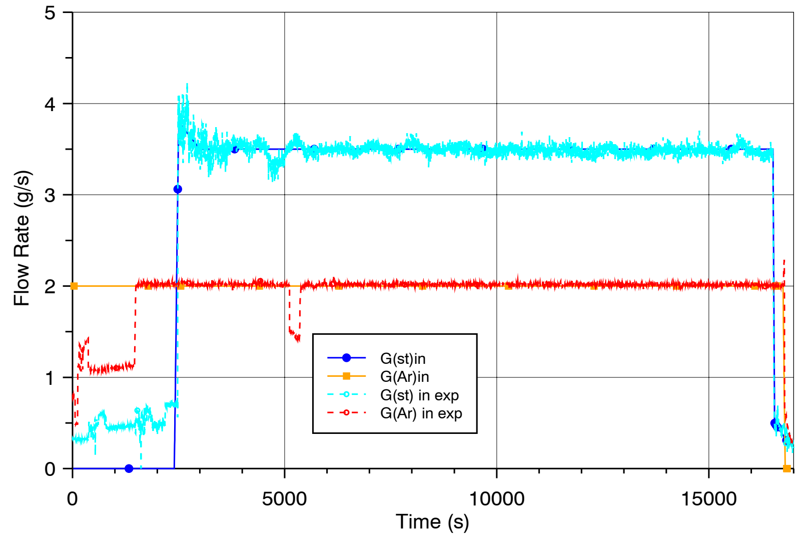
- Power
  - as experimental data
  - ext. resistance 1.0 mΩ/rod
- Mass flow rate
  - as experimental data
  - start of bottom quench 40s delayed to compensate the different water inventory in lower test section at start of bottom flooding



Electric Bundle Power



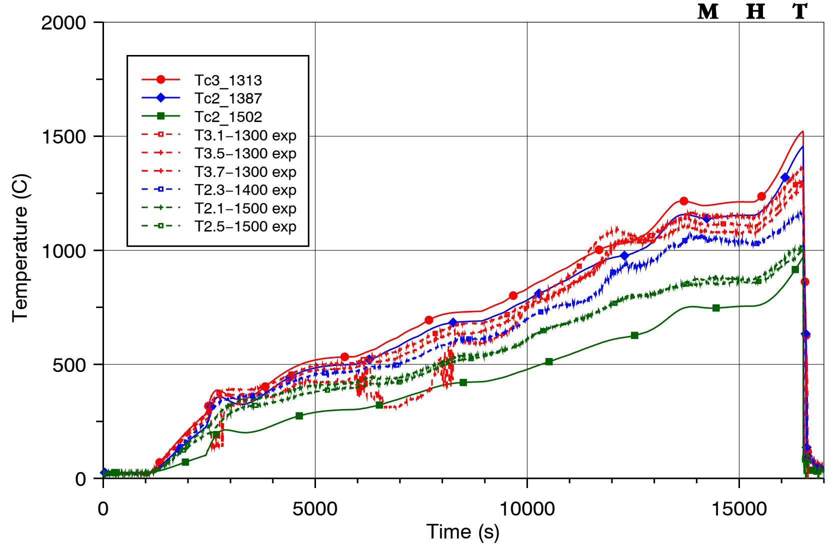
Liquid Flow Rate of Bottom and Top Flooding



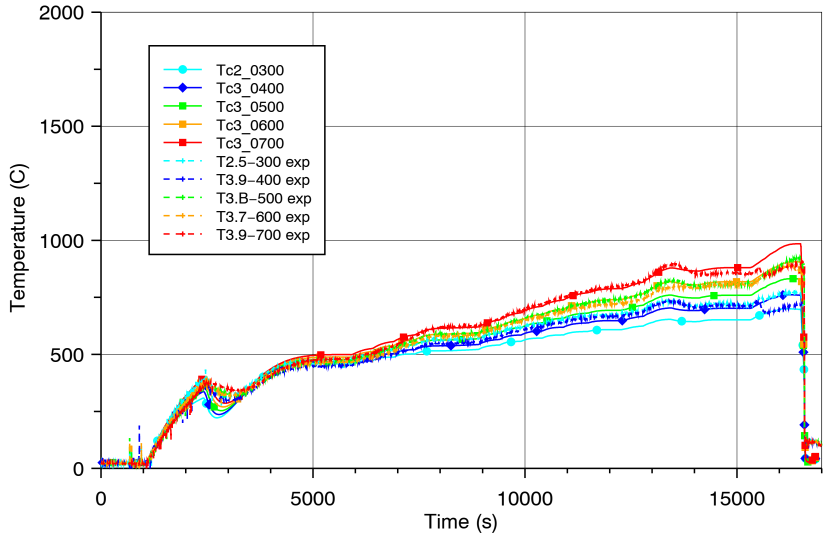
Inlet Flow Rate of Argon and Steam

Cladding temperatures

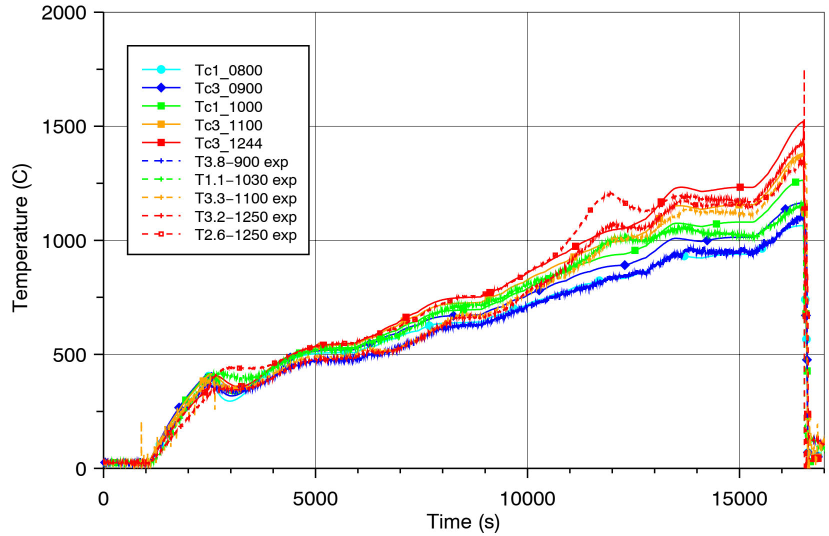
- lower bundle region:
  very good agreement besides temperature decrease of measured data at ~ 15500s
- medium and top bundle region:
  good agreement besides test data at ~ 12000s (reason for 'hump' in exp.?)
- Maximal temperatures in calculation slightly above measured values (1500°C)



Cladding Temperature (1300−1500mm)



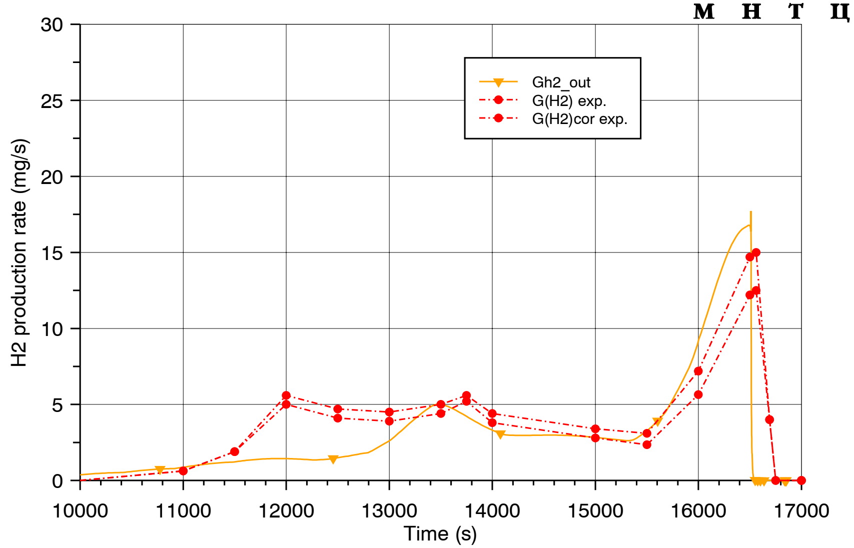
Cladding Temperature (300−700mm)



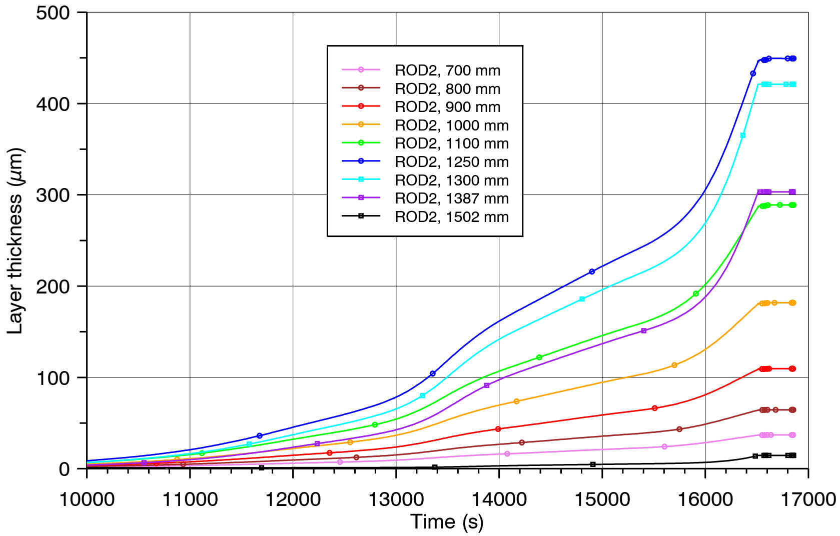
Cladding Temperature (800−1250mm)

Hydrogen and oxide layer

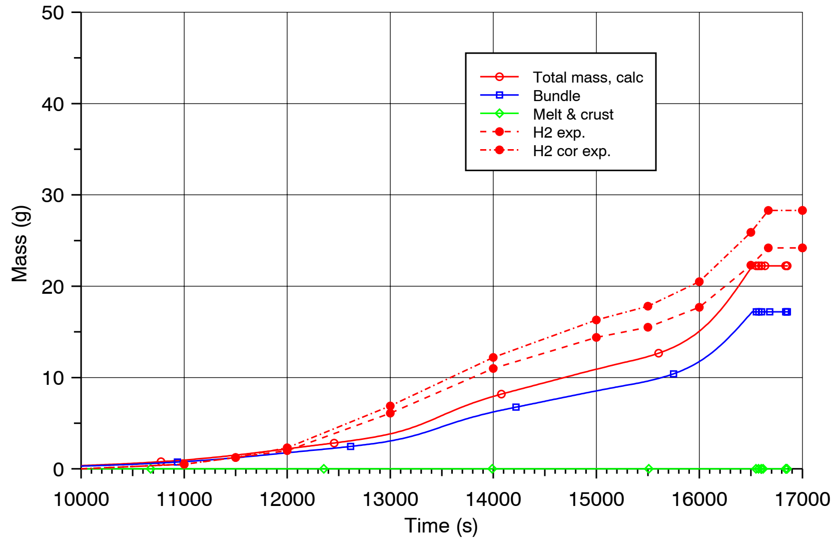
- hydrogen generation is simulated in good agreement with test data (besides period at ~12000s) with Leistikow / Prater-Courtright oxidation model
- oxidation with Sokolov kinetic data leads to underestimation of hydrogen mass
- resulting hydrogen mass: 22.3 g (measured: 24 – 28 g)
- calculated cladding oxide layer thickness at end of pre-oxidation phase max. ~250 µm (assumed as ~150 – 200 µm in test)



Hydrogen Generation Rate



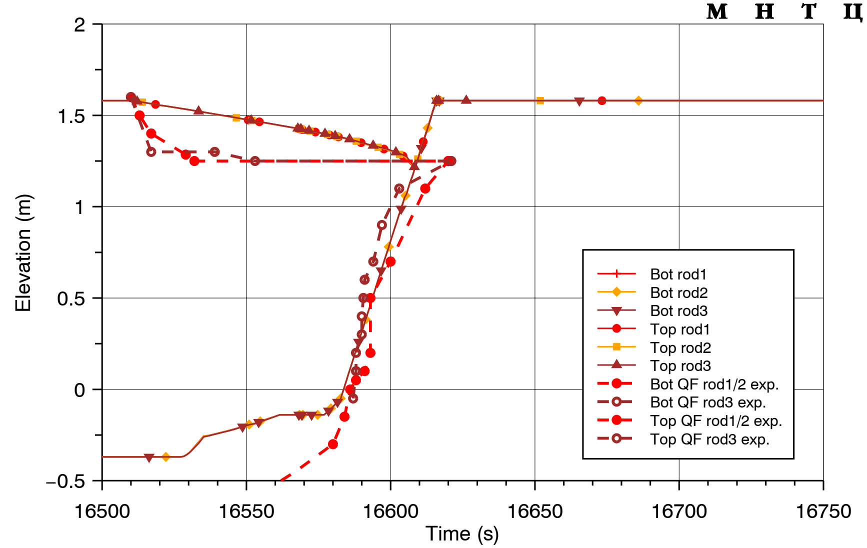
Oxide Layer Thickness



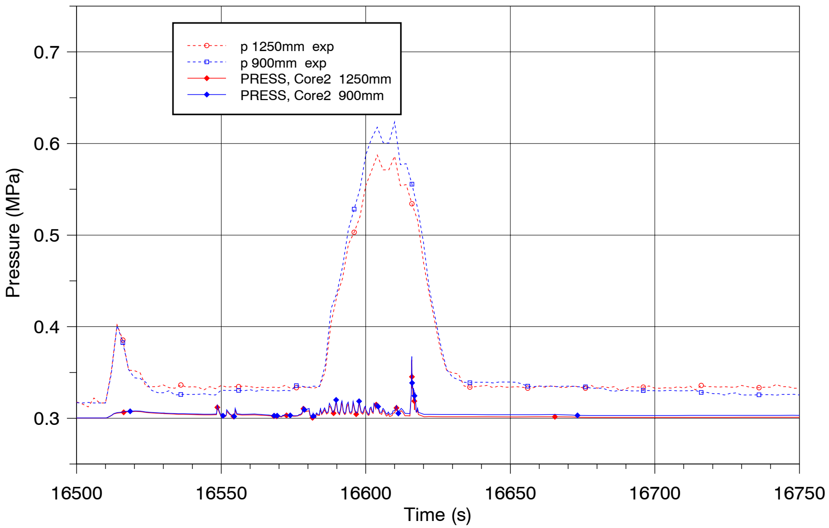
Total Hydrogen Generation

Quench front, discharged mass, and pressure

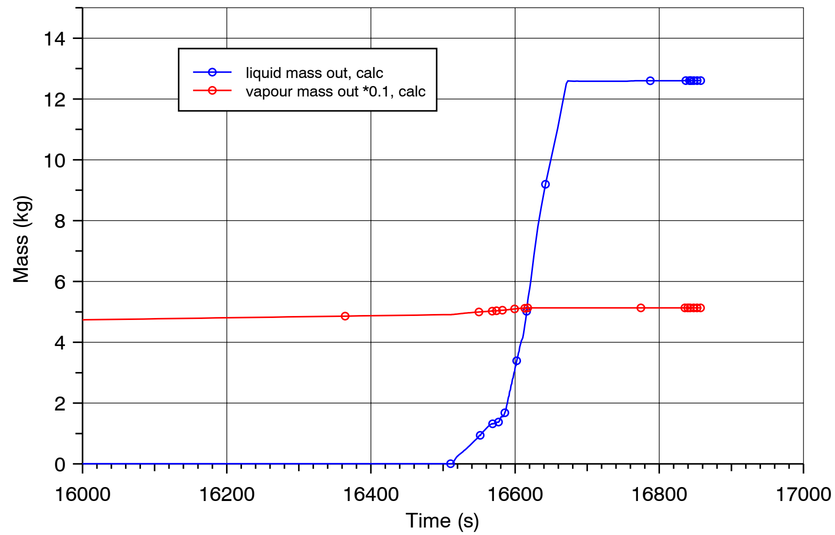
- initial cooling below heated region too fast, above heated region too slowly
- good agreement of quench front progress in heated region (0 – 1.275m)
- time point of total cooling (~16620s) and of intersection (1250 mm) well predicted
- water discharge during quench ~ 13 kg
- measured pressure increase after start of bottom flooding is not calculated in spite of evaporation rates comparable to the test (20 – 14g/s)



Top and bottom quench front rods



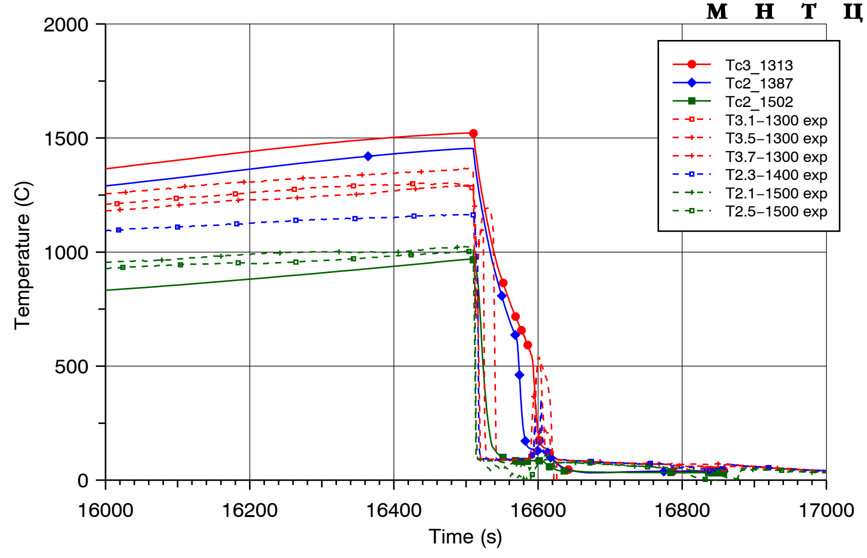
Pressure in Bundle



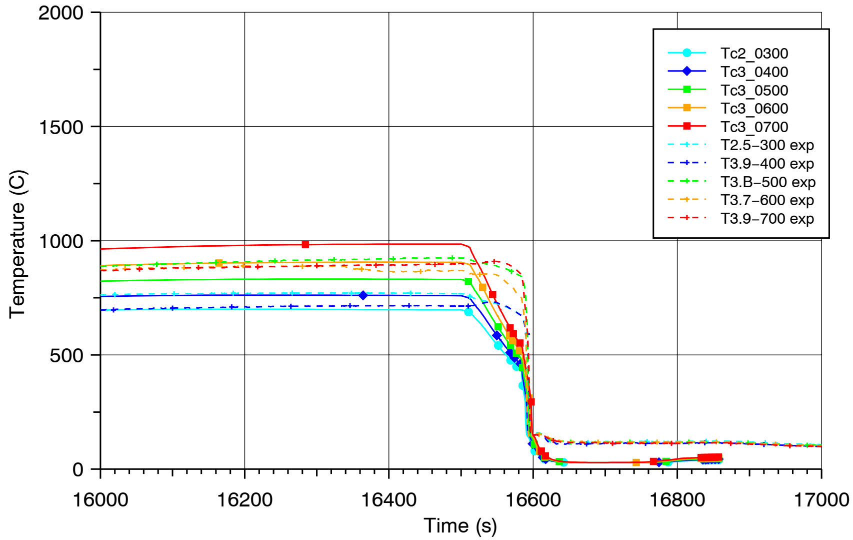
Discharged Liquid and Vapour Mass

Temperatures during quench with standard entrainment

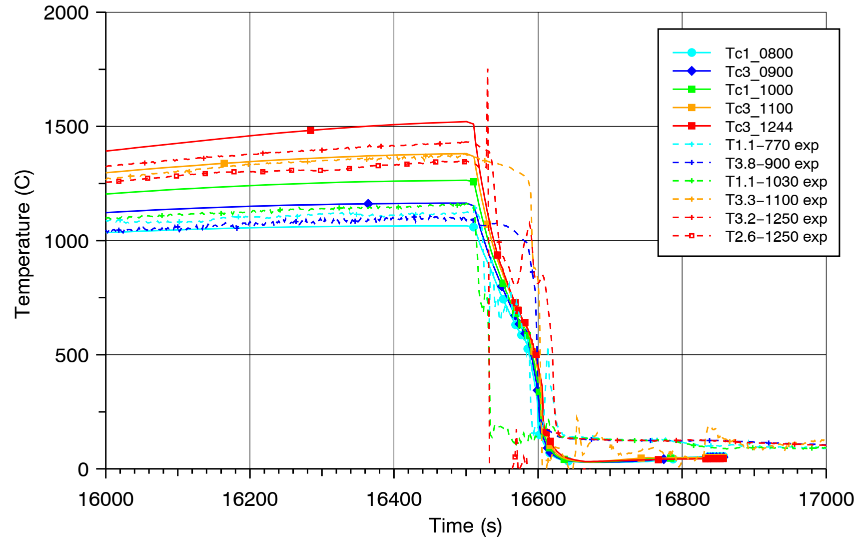
- lower bundle region:
  fast pre-cooling of the rods as liquid injected at the top, temperature drop too fast
- medium and top bundle region:
  average behaviour of cool down is calculated in agreement with measured temperatures
- some local effects measured cannot be calculated by the code



Cladding Temperature (1300–1500mm)



Cladding Temperature (300–700mm)



Cladding Temperature (800–1250mm)

Modelling of interfacial friction for vertical flows

- Bubbly, slug and churn flows:
  - Interfacial friction coefficient C_i calculated as a function of drift-related parameters obtained from the full-range flooding based drift-flux model:

$$C_i = \alpha\,(1-\alpha)\,\frac{g(\rho_L-\rho_G)}{v_{D,j}^2}$$

$v_{D,j}$ = difference of local drift velocity

- Annular, annular-mist flows:

$$C_i = \frac{1}{2}(1-\alpha)\,\rho_G\,\sqrt{\frac{g\,(\rho_L-\rho_G)}{\sigma}}\left(\frac{1+17.67\alpha^{2.6}}{18.67\alpha^3}\right)^2$$

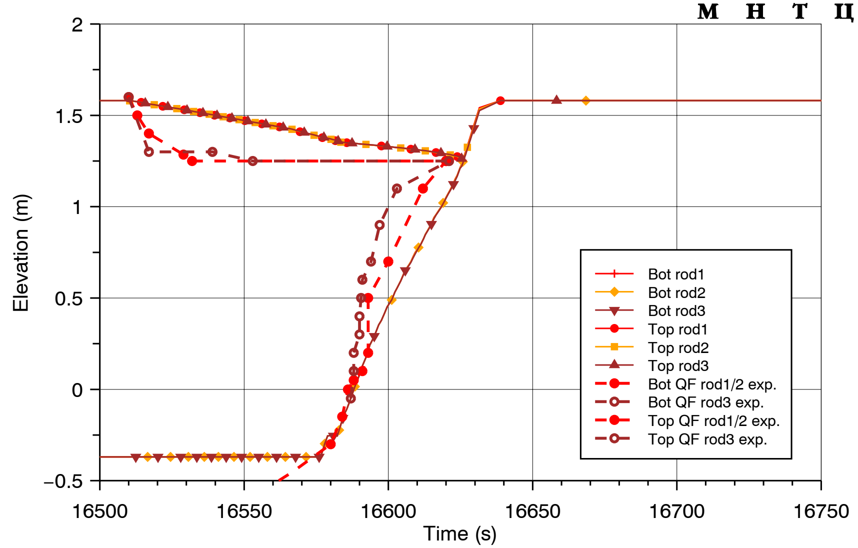
σ = surface tension

- Transition between churn flow and annular flow is determined by entrainment fraction

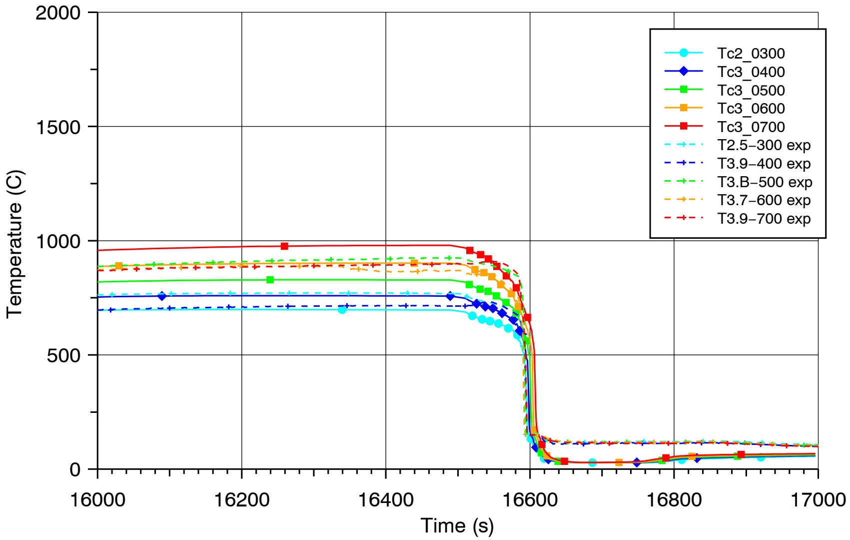
- Proposed change for PARAMETER SF2 additional calculation:
  - Reduction of the limiting steam superficial velocity for onset of entrainment
  - Increase of interfacial friction coefficient for annular flow and annular-mist flow

Quench front and temperatures during quench with earlier onset of entrainment

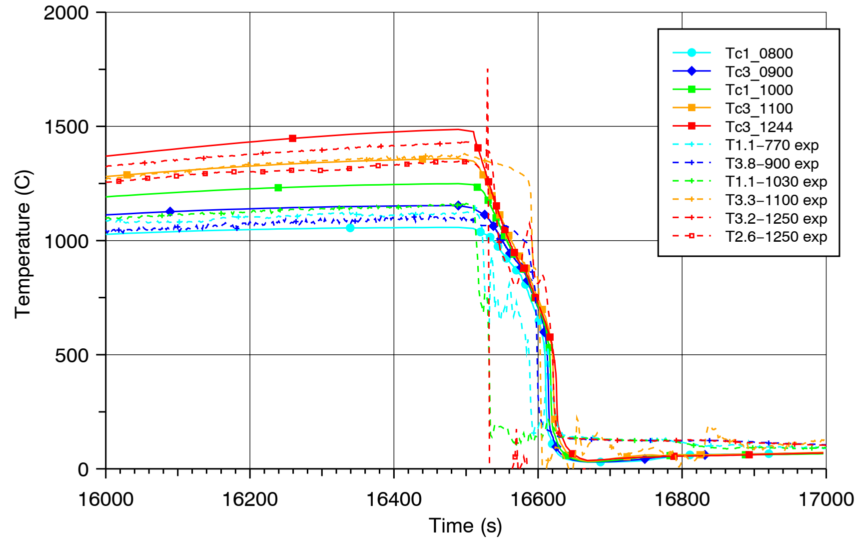
- calculated quench-fronts in lower bundle region are calculated in better agreement with test data
- lower bundle region:
  decreased pre-cooling of the rods –
  cooling behaviour is calculated in agreement with measured temperatures
- medium and top bundle region:
  less change compared to previous calculation



Top and bottom quench front rods



Cladding Temperature (300−700mm)



Cladding Temperature (800−1250mm)

Conclusions

- Post-test calculation of PARAMETER SF2 test with ATHLET-CD results in an overall good agreement between calculated temperatures and measured data
- Hydrogen generation is underestimated by the zirconium oxidation correlation of Sokolov
- Kinetics of Leistikow / Prater-Courtright lead to a well predicted hydrogen mass
- Due to delayed onset of entrainment, the liquid injected at the top drops down too fast and the pre-cooling in the lower bundle region is too strong
- Increased interfacial friction for annular flow and annular-mist flow allows a better prediction of the cooling at lower elevations
- The liquid mass collected in Tank 6 would allow to evaluate the discharged water mass (13 kg)
- Additional information on condenser tank (geometry and nominal operation conditions) is needed for improved simulation of bundle pressure increase after quench initiation