Pre-Test Analysis of QUENCH-20 BWR-Bundle with ASTEC

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Content

- Motivation
- Quench-20 experiment
- ASTEC Modeling & Input
- Calculation Result & Analysis
- Summary

Motivation

- The new Version of ASTEC, It's capabilities to simulate BWR-bundle tests;
- Pre-test Simulation Results to support experiment staffs;
- To review the ASTEC capabilities to simulate BWR Plants.

Quench-20 Experiment

Quench Experimental Facility

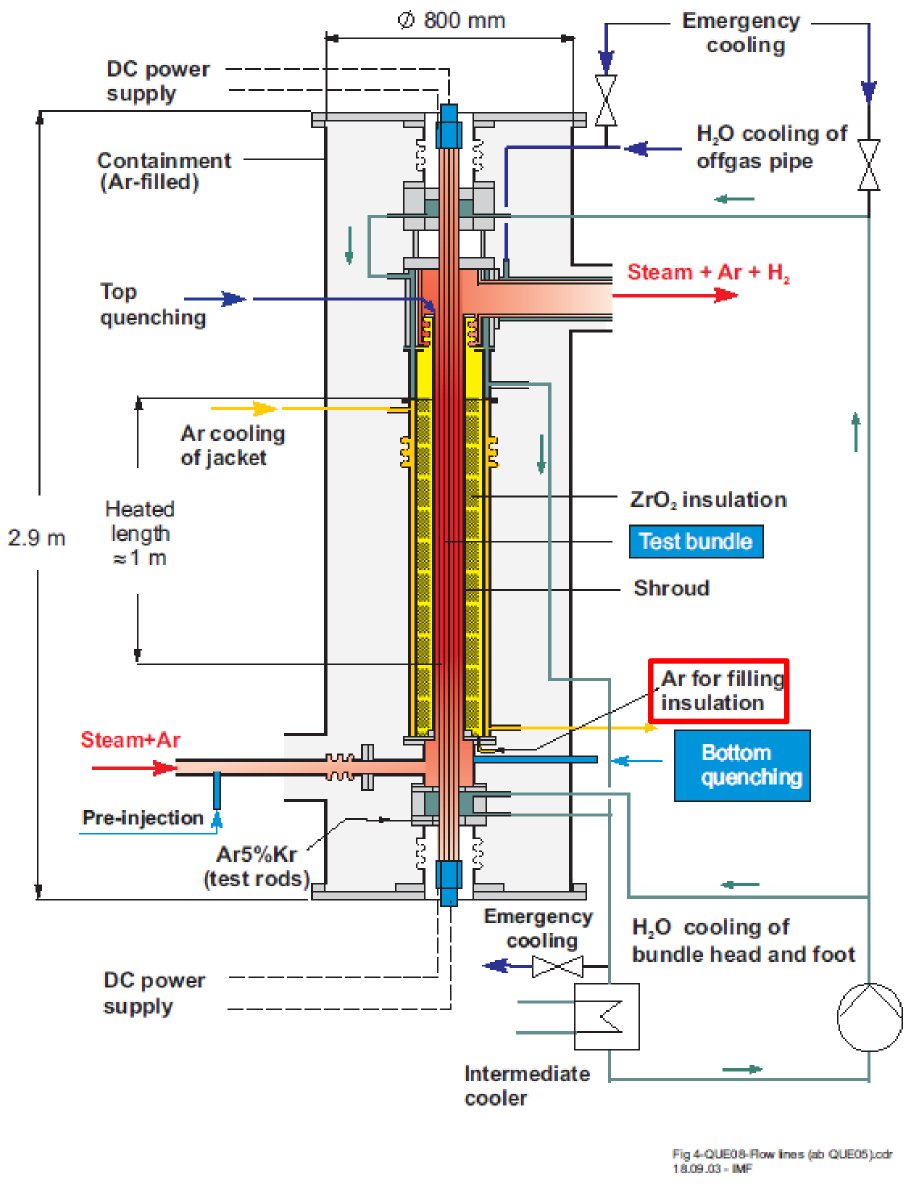

Fig. 4: QUENCH test section; flow lines

- The main component of the QUENCH facility is the test bundle
- Superheated steam + argon as a carrier gas enters the bundle at the bottom
- The argon, the not consumed steam, the generated hydrogen exit the bundle at the top.
- The reflooding water enters the test section through a separate line at the bottom of the bundle

Pre-test simulation of QUENCH-20 (SAFEST)

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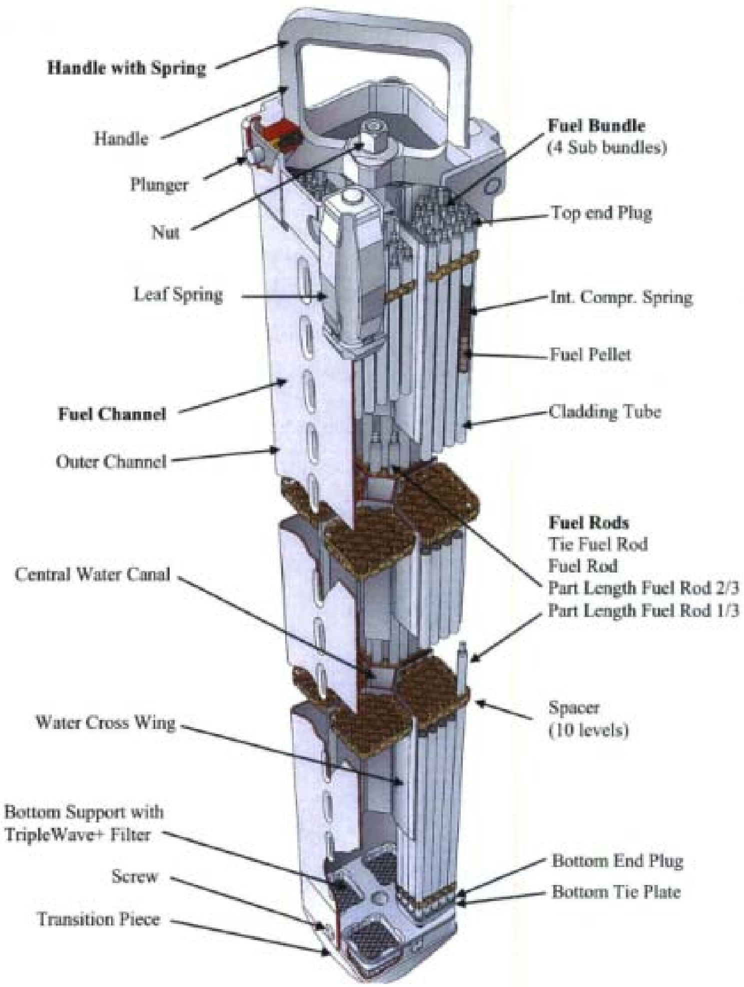
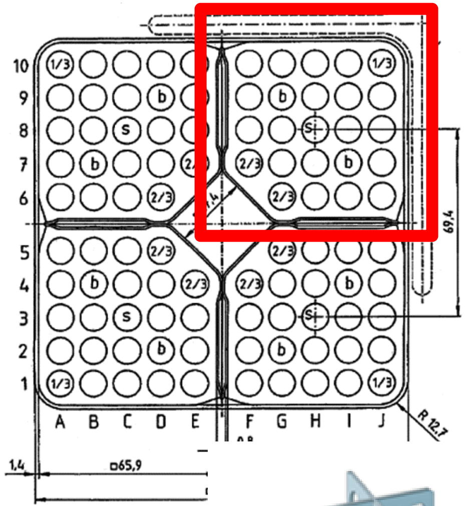
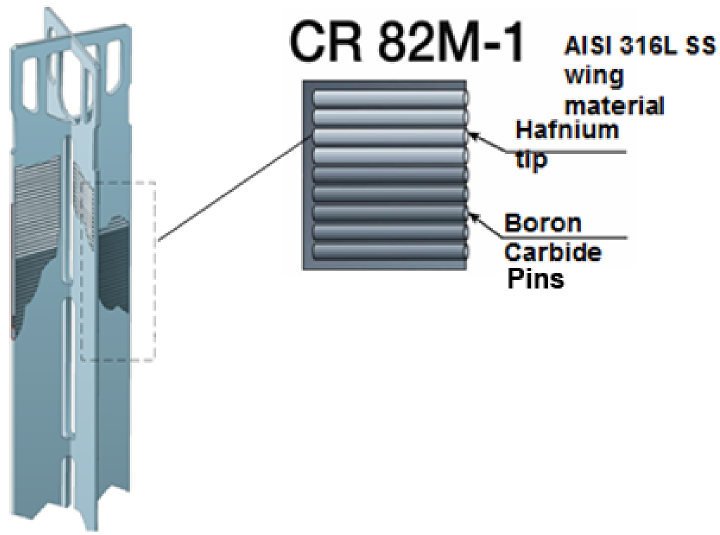




SSM proposal: study of high temperature degradation of BWR assembly mock-up in QUENCH facility (melt formation due to eutectical material interaction inside absorber cross)



Assembly SVEA-96 Optima

Absorber cross blade

QUENCH-20: suggested test bundle composition (¼ SVEA-96 OPTIMA2 assembly)

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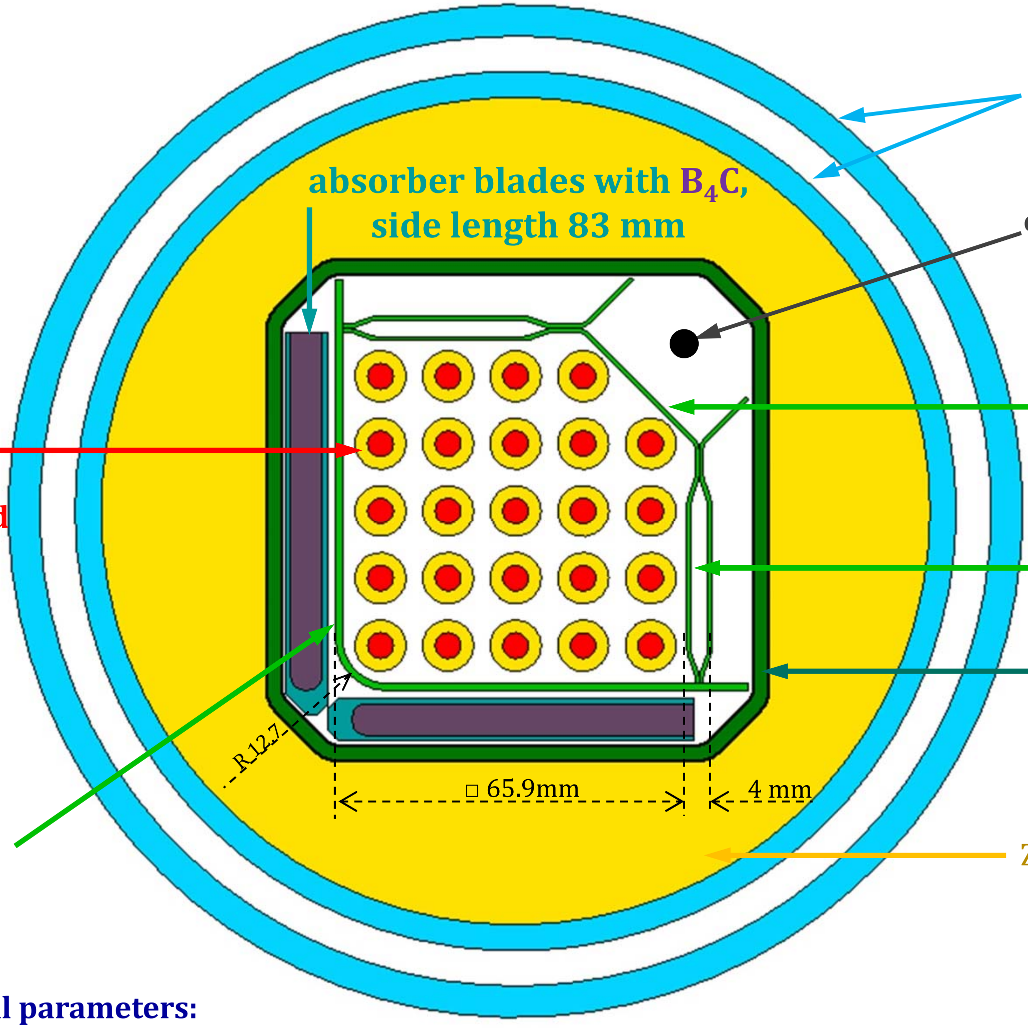

Geometrical parameters:

- bundle pitch 12.898 mm;
- outer diameter of claddings 9.84 mm;
- thickness of claddings 0.605 mm;
- absorber blades: thickness 8.05 mm

- cladding length 2500 mm
- absorber and channel box lengths 1600 mm

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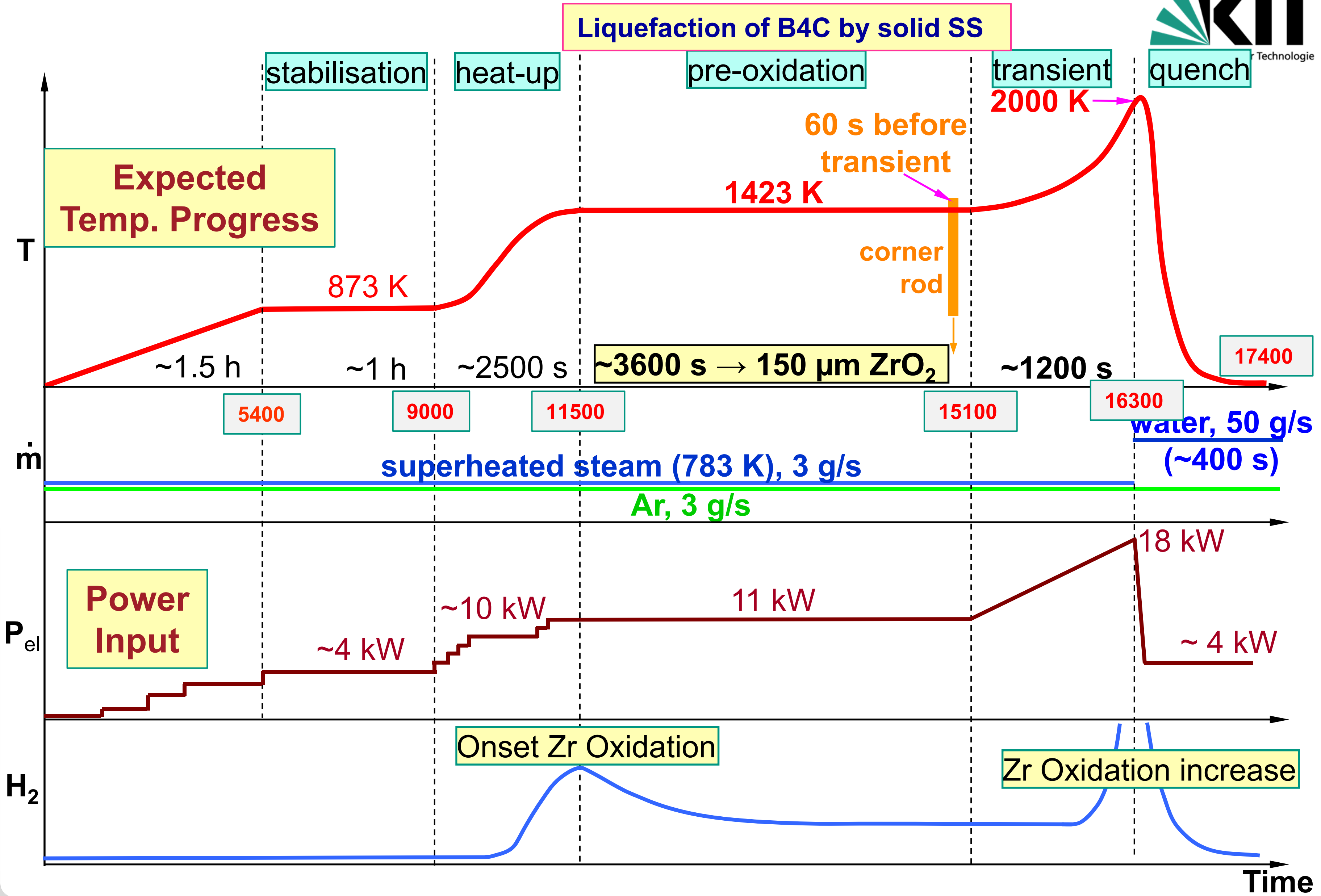
Suggested scenario for QUENCH20-SAFEST



Core degradation modelling

Main phenomena to take into account

T (K)

LATE PHASE (degraded)

3120 UO_2 melting
2960 ZrO_2 melting
2800 UO_2-ZrO_2 dissolution
2720 B_4C melting

2500

EARLY PHASE (intact)

2030 Onset of Zr melting
1850 Zr oxidation increase
1730 Stainless steel melting
1670 Eutectic interactions
SIC - Zr
1500 S.Steel - Zr

1420 B_4C - S.Steel dissolution
1300 Onset of Zr oxidation
1200 Clad burst
1100 SIC control rod melting

CORE COLLAPSE AND RELOCATION

MOLTEN POOL FORMATION

PARTIAL FUEL MELTING
CORE BLOCKAGES
(Ceramic melts)

LOCAL
CORE DAMAGES
(metallic melts)

FISSION PRODUCT RELEASES

H2 Production Rate ↗

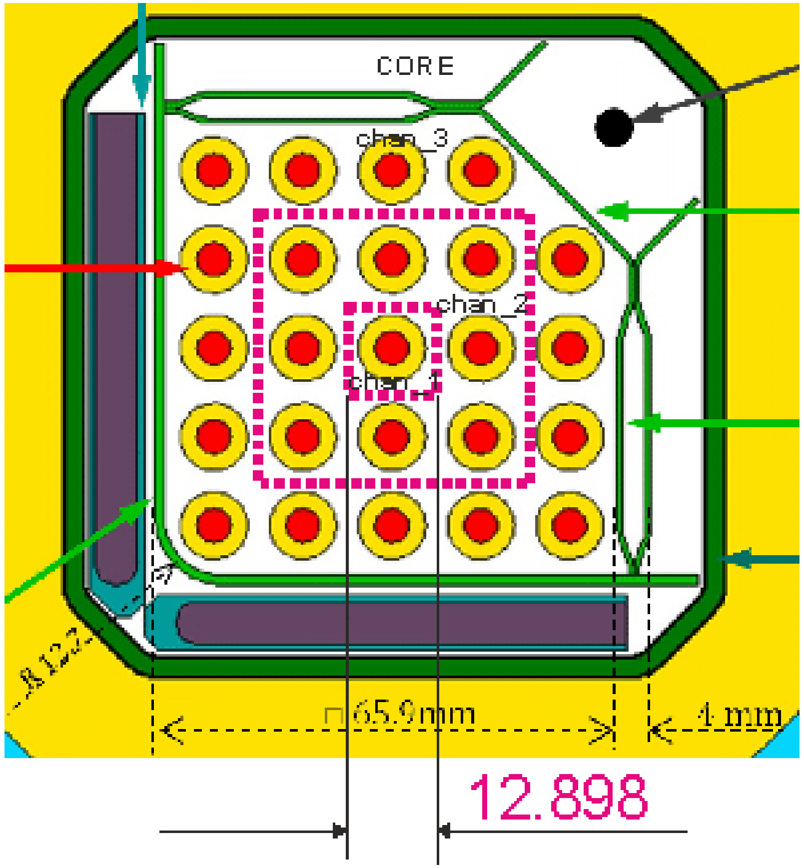
CR Cladding melting

Liquefaction of B4C by solid SS

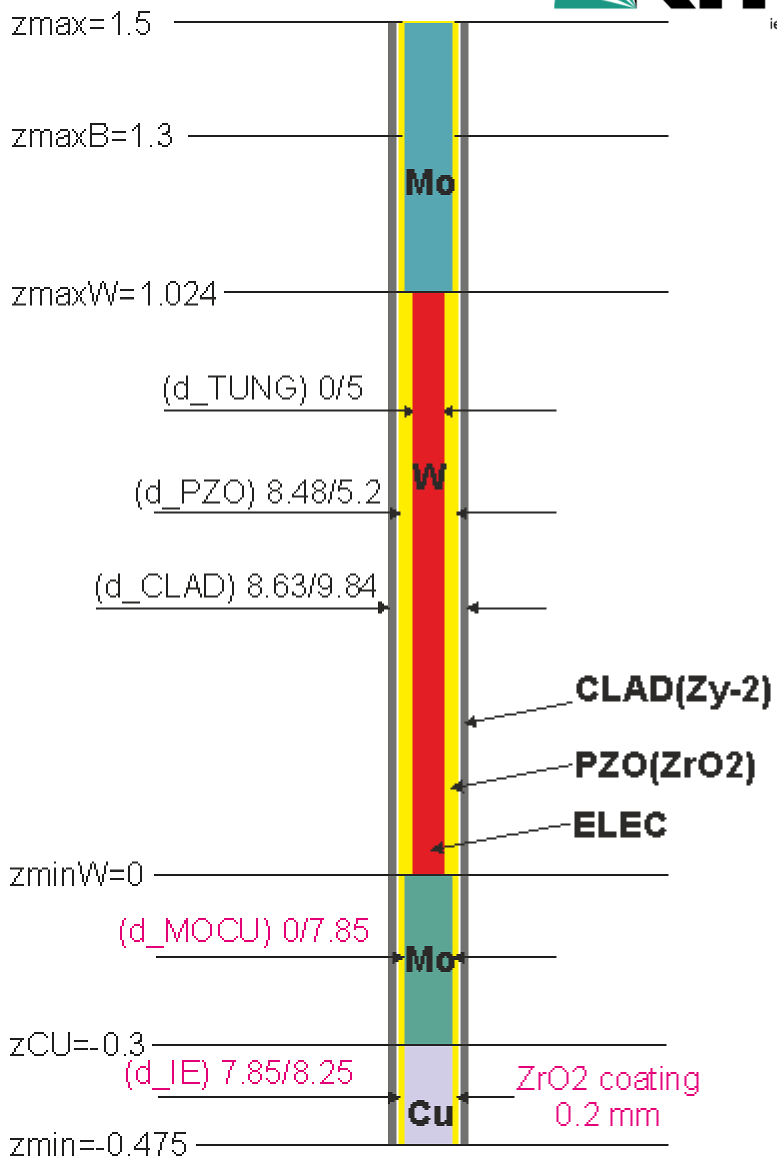
H2 Production

ASTEC Modeling & Input

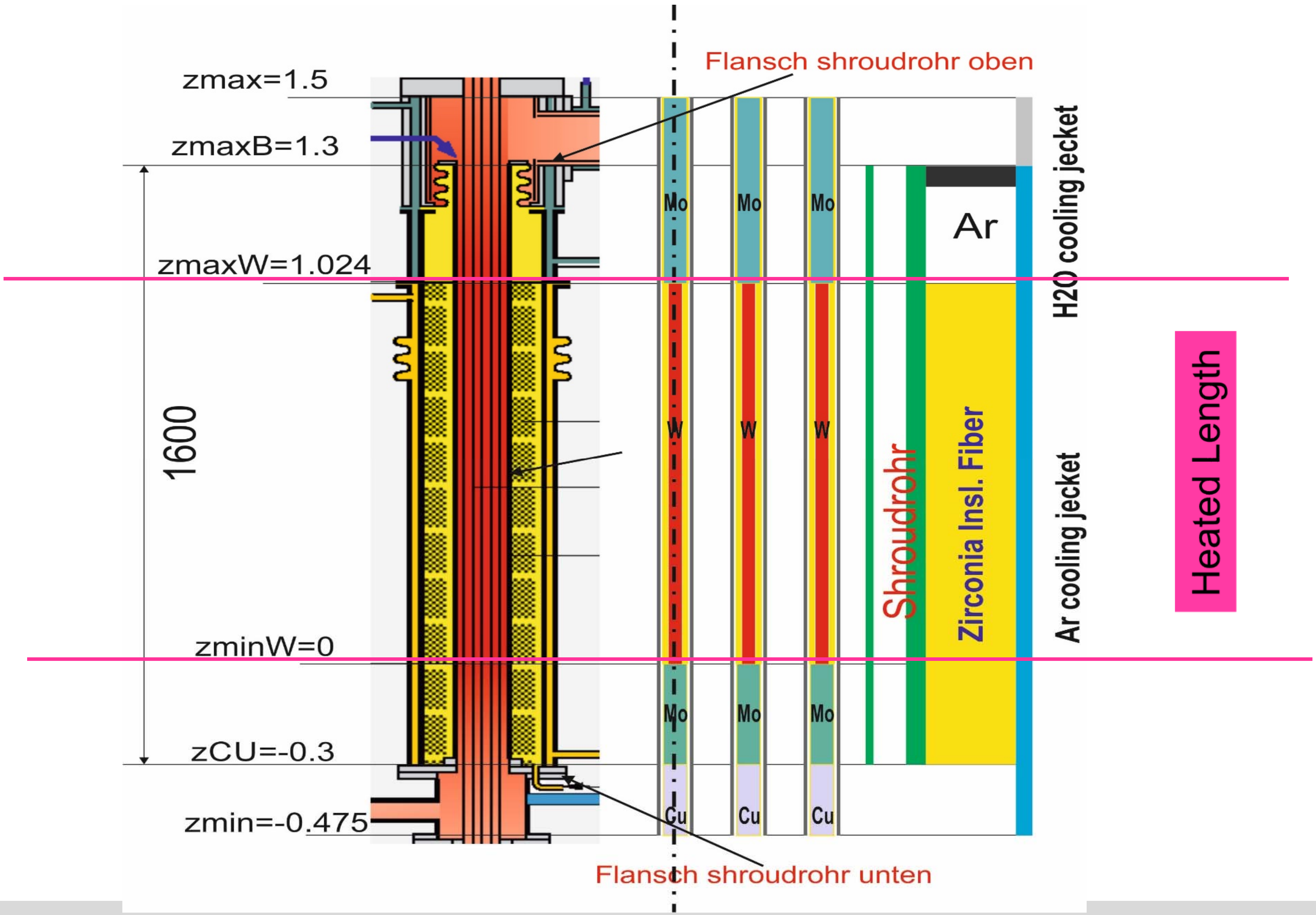
Quench-20 Cross Section and Heated Rod



3 Channels



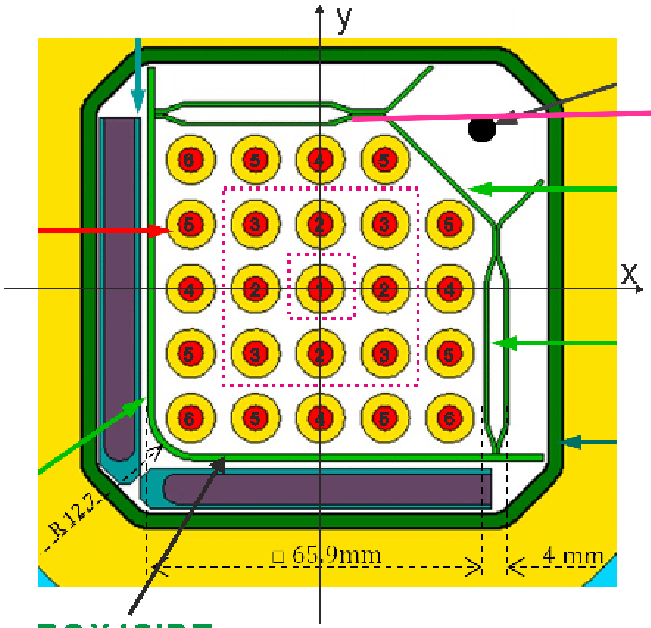
Quench- 20 Bundle Axial Arrangement

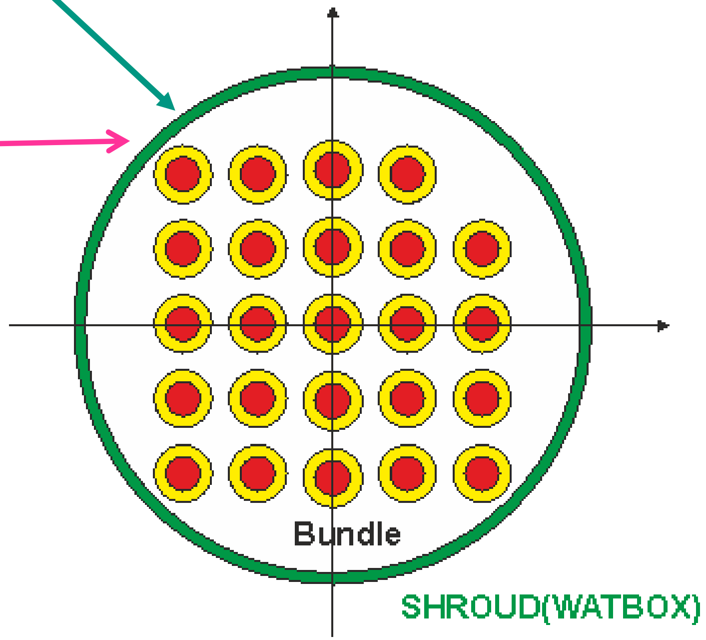


HT: Radiative heat exchanges in a bundle

STRU RADB

[bundle]: geometic parameters
[bundle]: location parameters
[**shroud**]: diameter; **Obligatory**: **cylinder**
[radiative model]: parameters

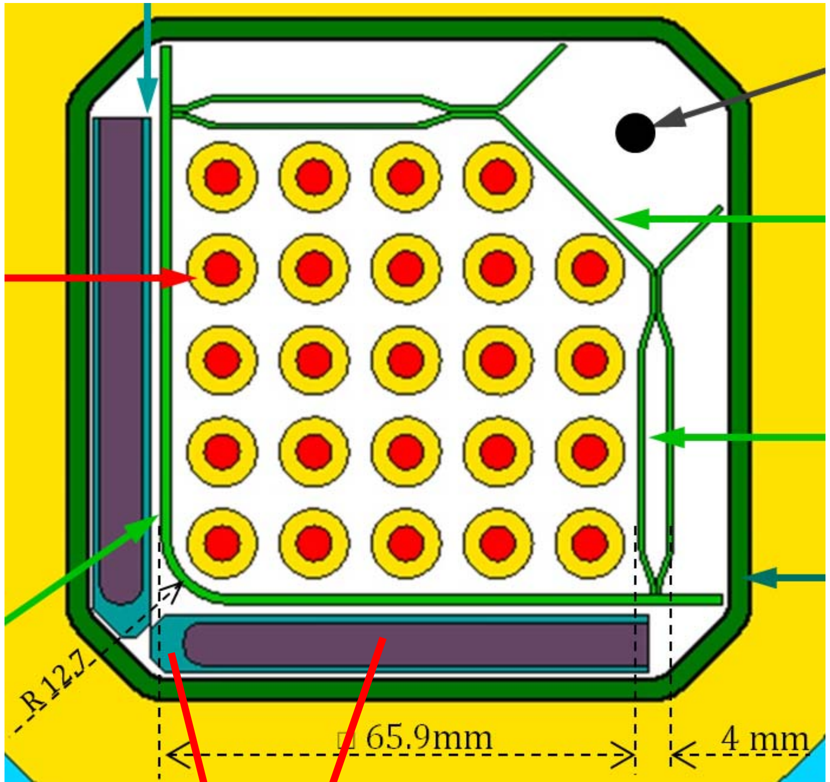




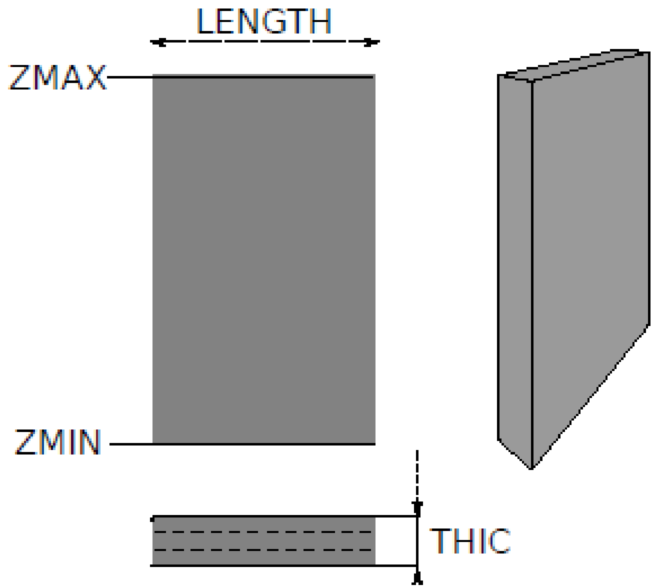
Shroud type: cylinder

Oxidation B4C & liquefaction of B4C by solid SS (1/4)

- **Oxidation of B_4C** module: **Vessel: BCOX**
- **B_4C – S. Steel** dissolution module: **Vessel: BCSS**



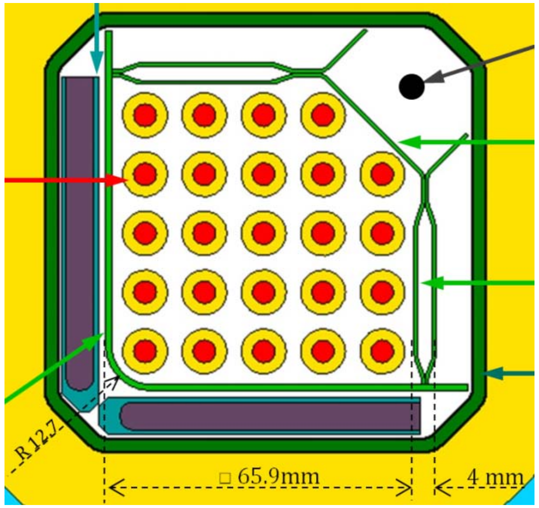
- **B_4C**
- **Stainless Steel**

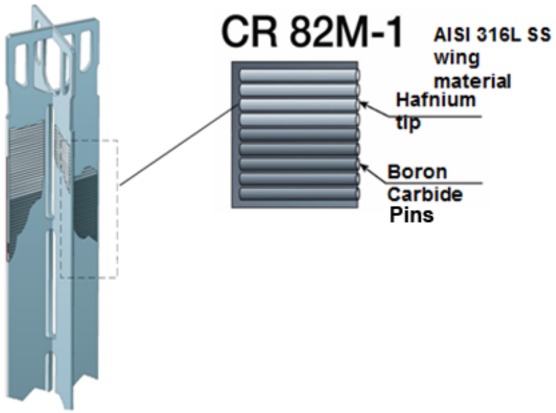


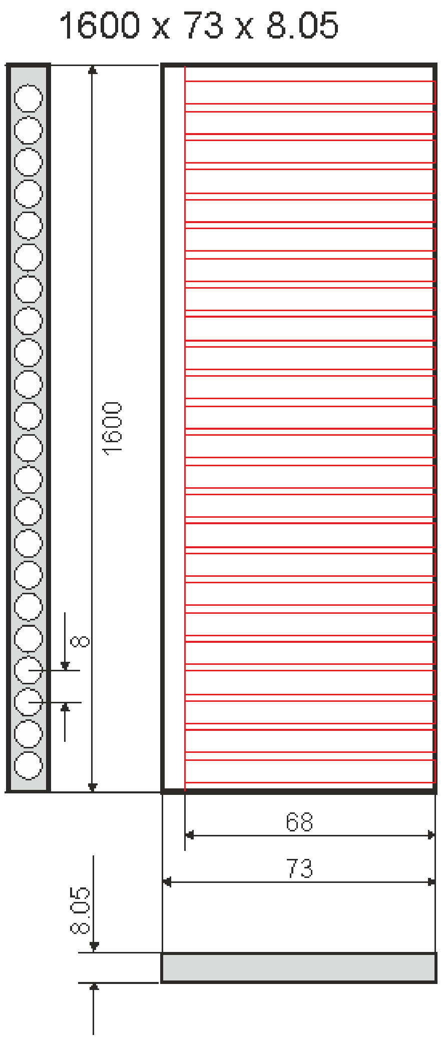
MACRO WALL

It is not possible: cylinder in wall .

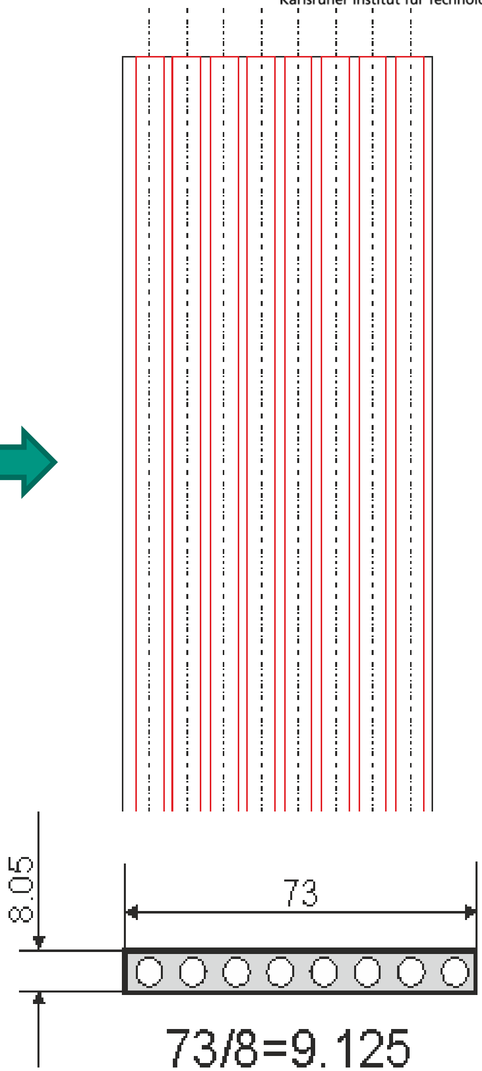
Oxidation B4C & liquefaction of B4C by solid SS (2/4)





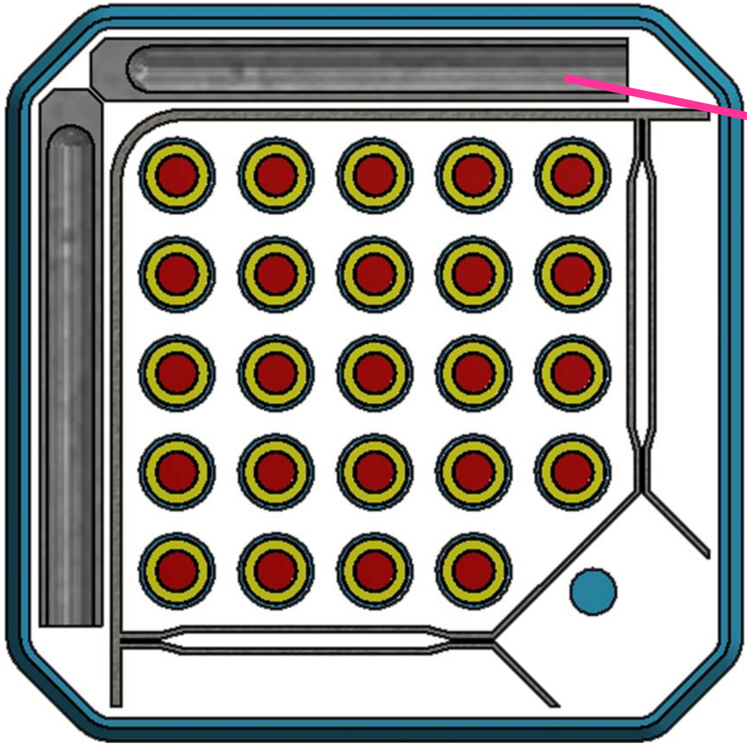


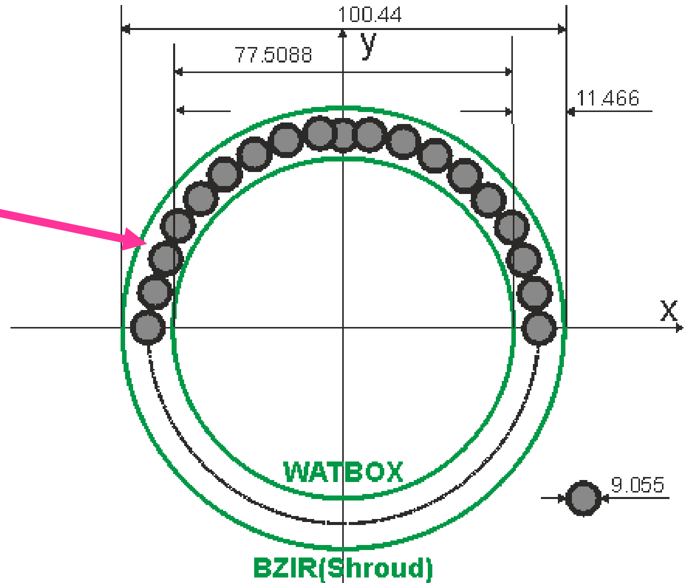
B_4C blade (Exp.)



B_4C blade (Model)

Oxidation B4C & liquefaction of B4C by solid SS (3/4)





WATBOX:d=77.5088 BZIR(Shroud)=100.44

CR_ring:d=(77.5088+100.44)/2=88.9744
r_CR_ring=44.4872

d=sqrt(8.05*8*4/Pi)=9.055

pitch=09.055

number=Pi*44.4872/pitch=15.43

Oxidation B4C & liquefaction of B4C by solid SS (4/4)

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WATBOX-Bundle-Shroud radiation Heat exchange

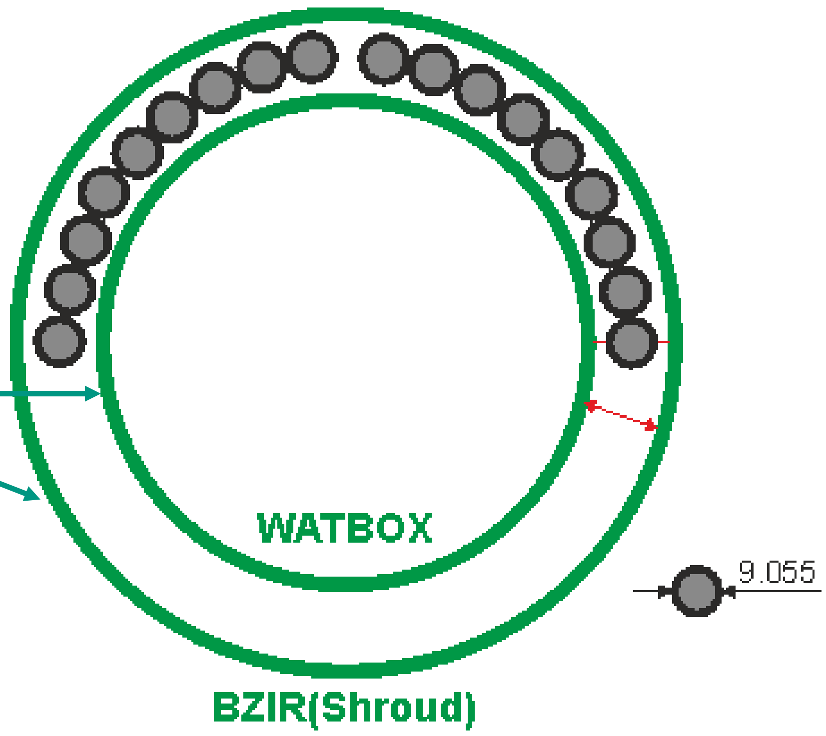
STRU RADB

[bundle]: **WATBOX: positon & geometry**

[bundle]: **CR cylinders: postions & geom.**

[**shroud**]:shroud ; Obligatory: **cylinder**

[radiative model]: parameters



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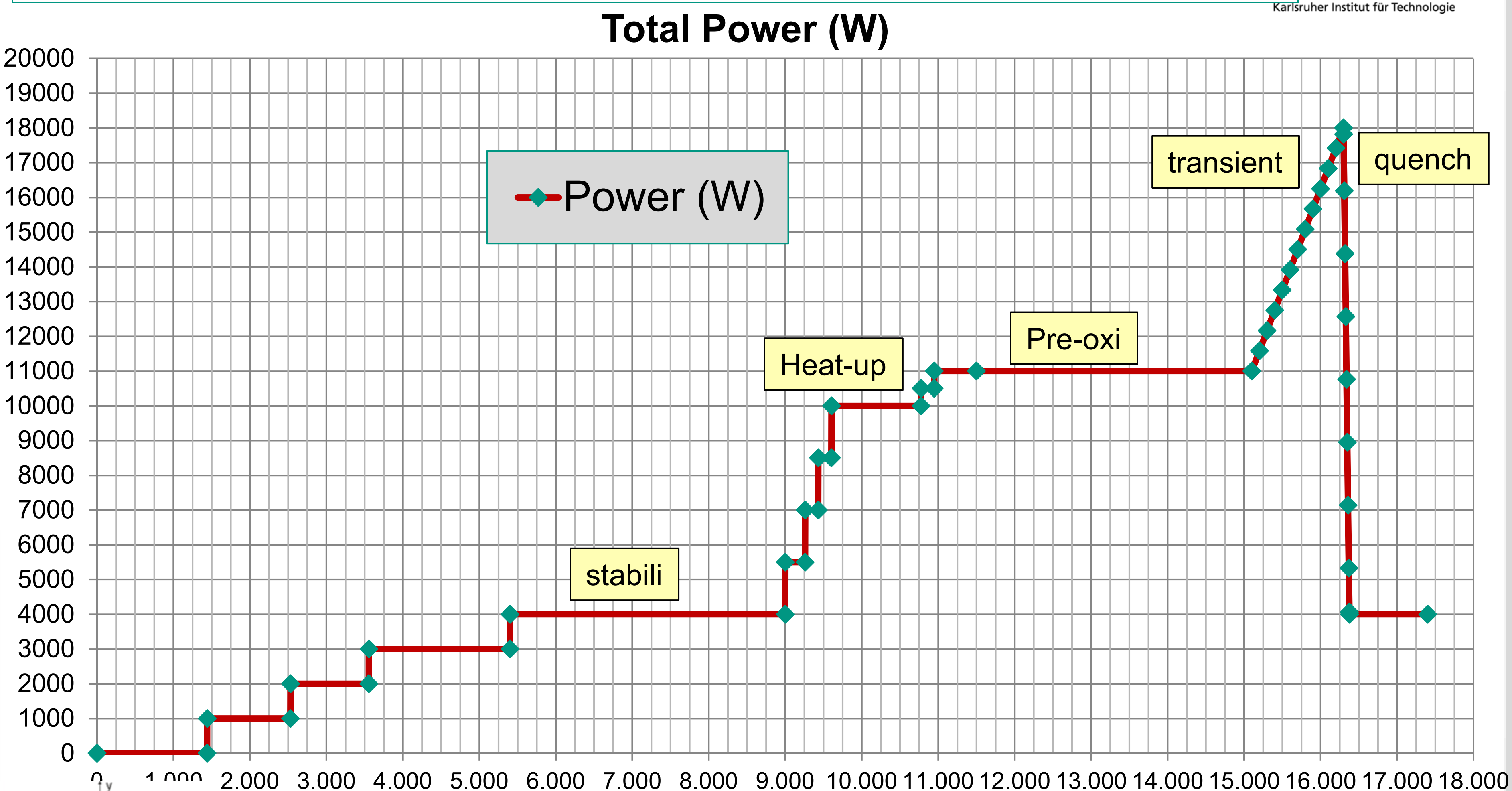
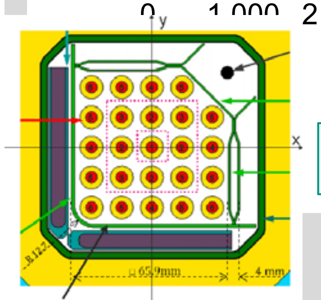
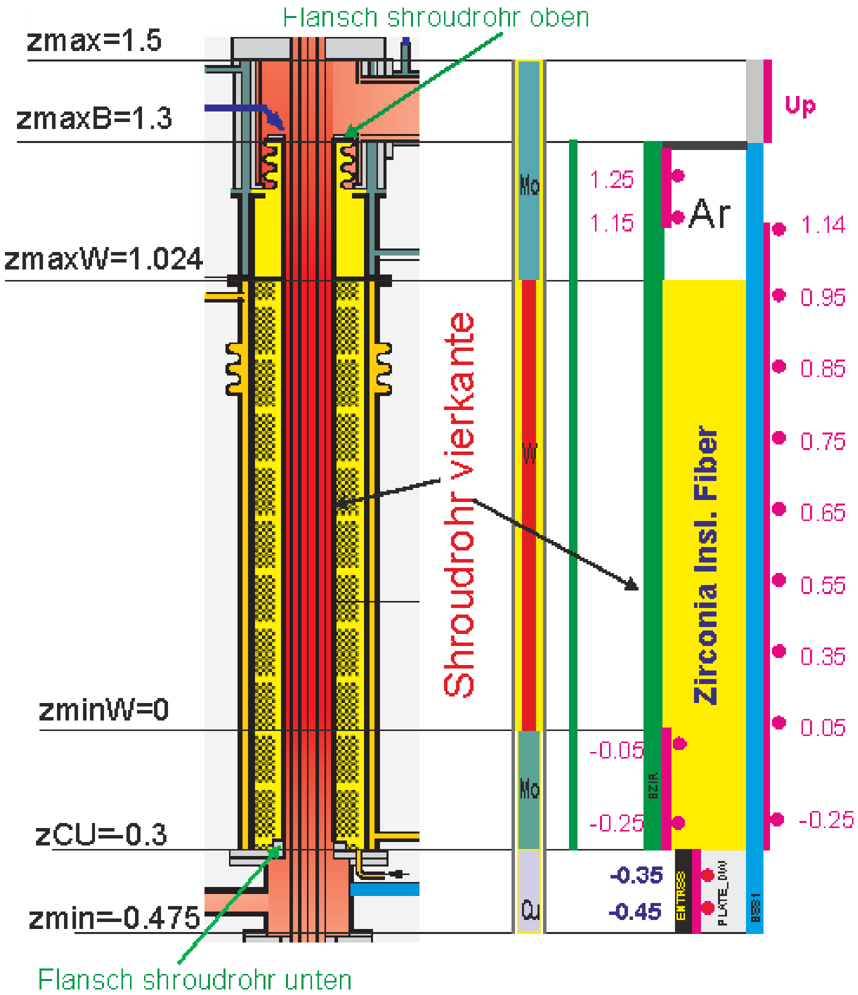
Total Power Input & Power distribution in bundles





Power in Channel (i)= Power * [(bundle_number_in_channel (i)] / [total_number]

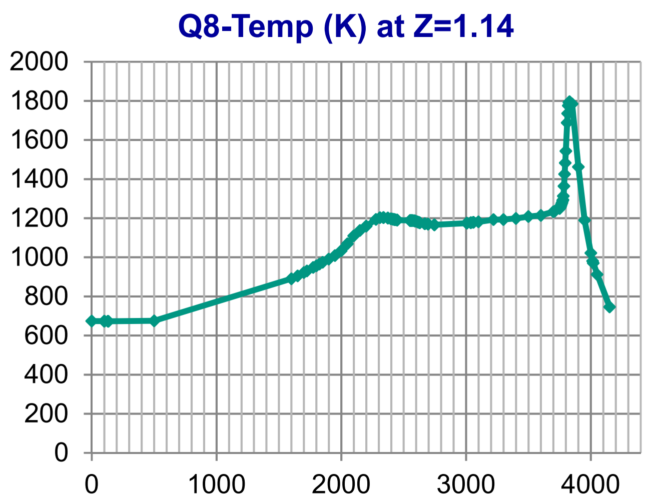
Thermal B.C.; BCTZ: Impose thermal conditions on a face of MACR at given elevations (1/2)

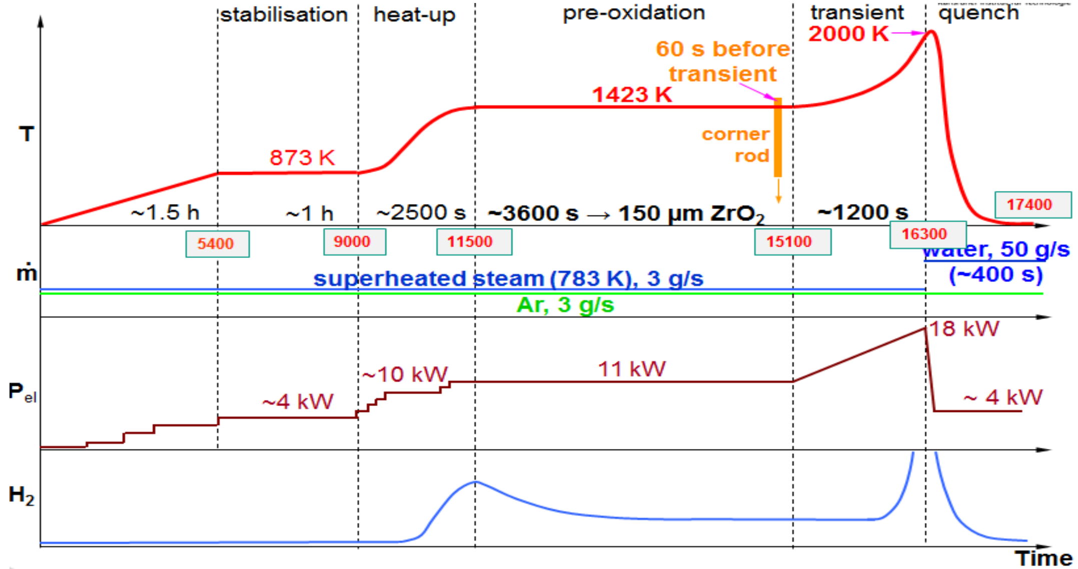


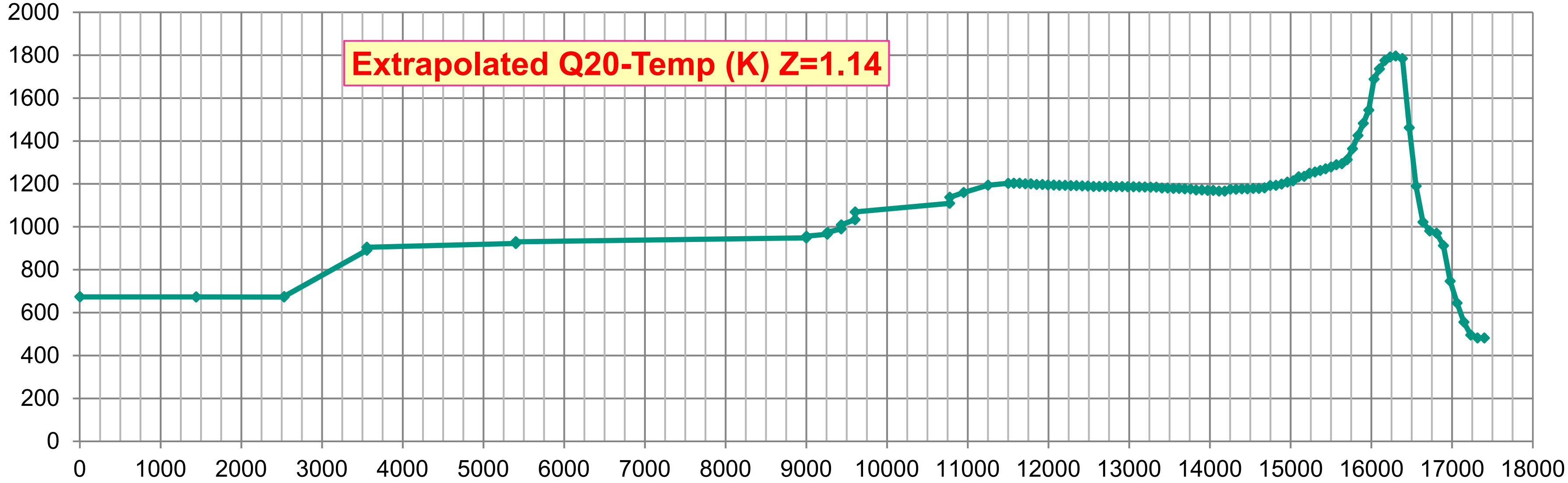
At given Macro Surface & Z-elevations:
e.g : cooling jacket z=1.14
{H(i), time(i), external_Temperature(i)}

```
MACR  ‚BSS1‘   FACE  ‚EXTERNAL‘
TYPE  ‚BCTZ‘
ZMIN  ZMAX    ! restrict domain
Z  1.14
SR1  H(i)      !  [W/(m2.K)]
SR1 INST       ! Instant (s)
SR1 TIMP       ! External meidum
               ! temperature (K)
```

Thermal B.C.; BCTZ: Impose thermal conditions on a face of MACR at given elevations (2/2)

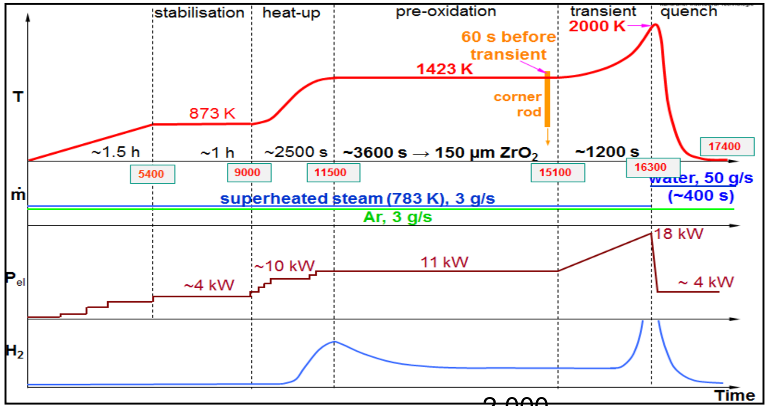


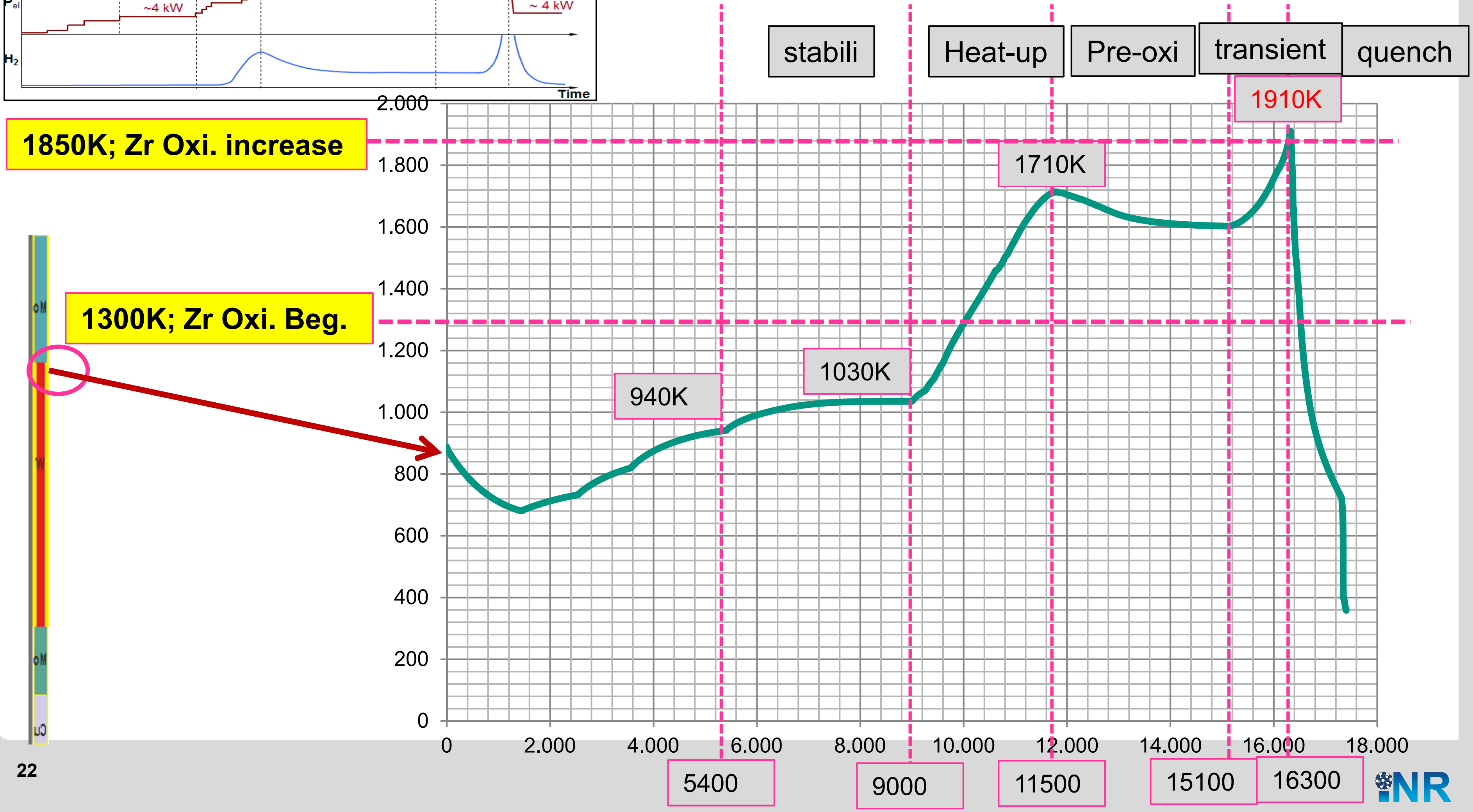




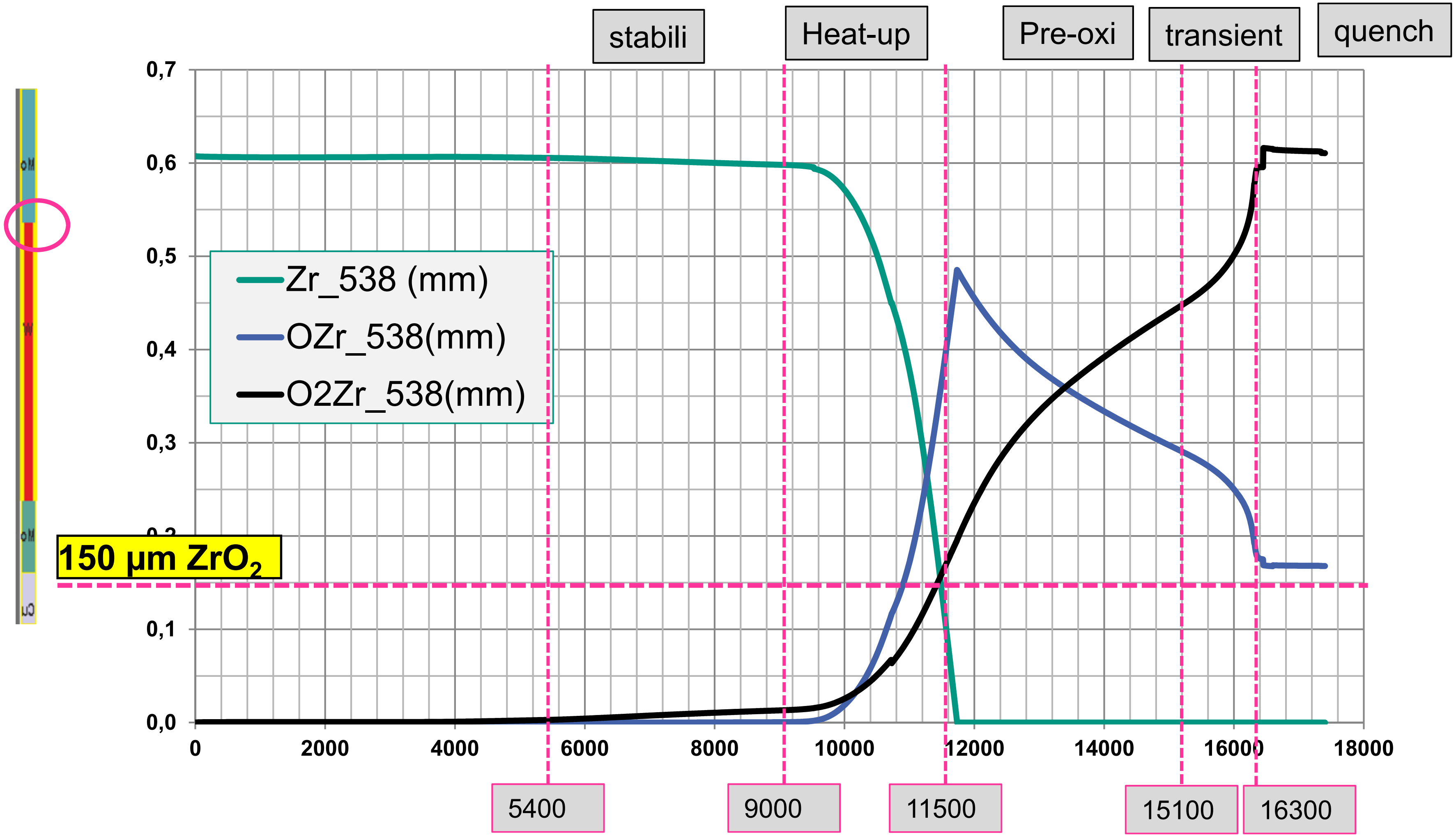
Calculation Results

Central Rod max.Temp. Development

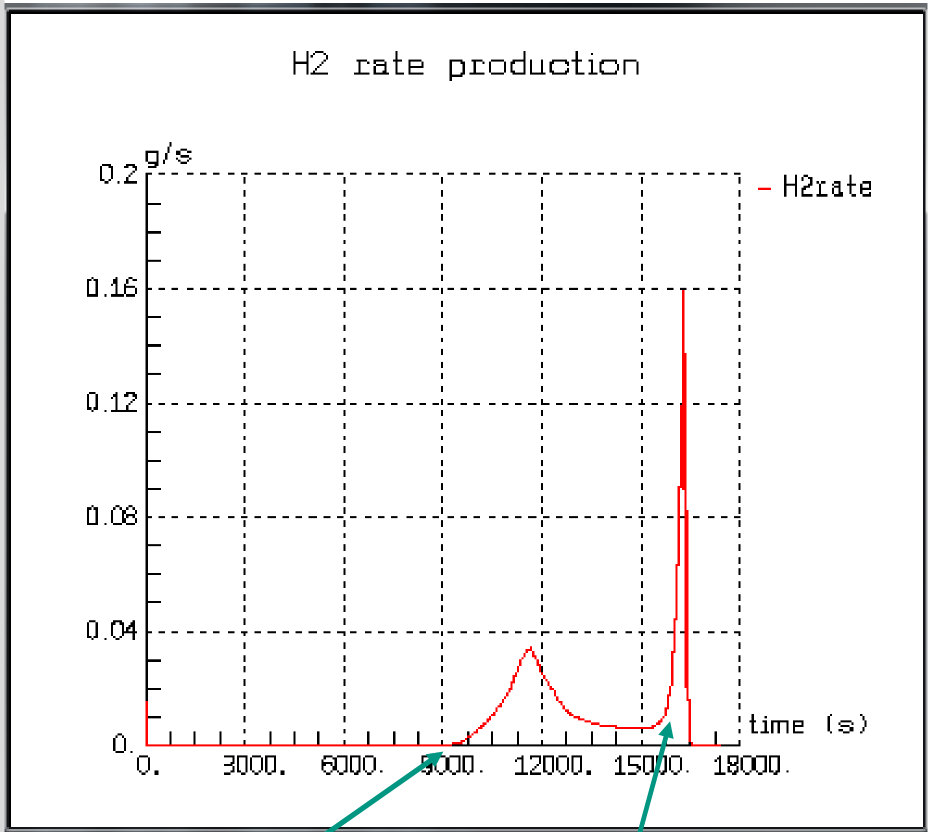


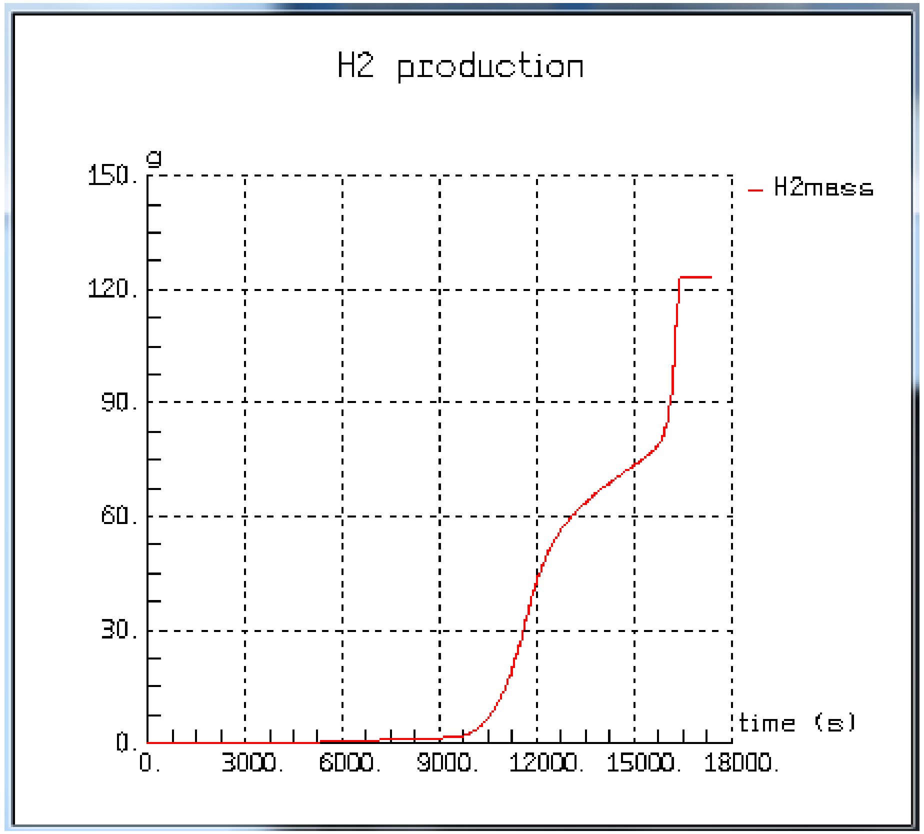


Heated Centr- Rod Zr, ZrO & ZrO2 Thicknesses



H2 production rate & Accumulated H2 mass



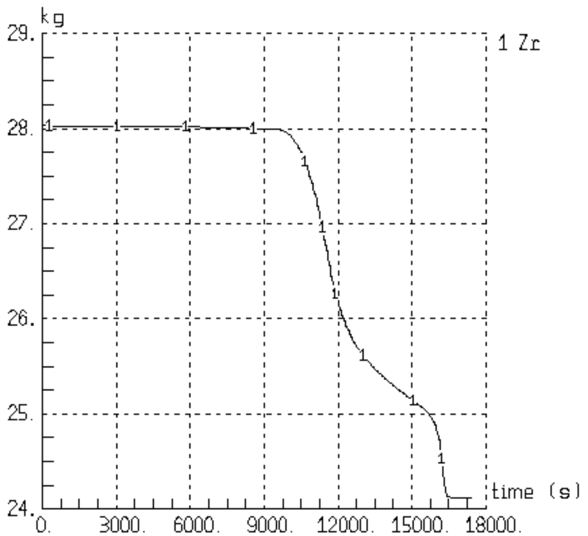


1850K, H2 Production Rate ↗

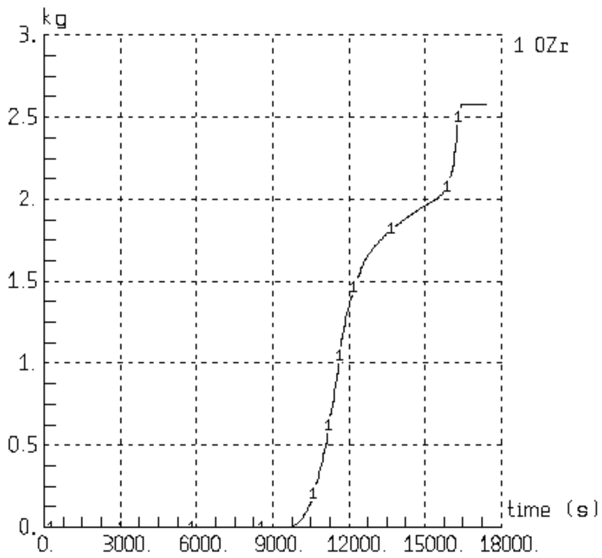
1300K: Onset of Zr Oxidation

Total Zr, ZrO & ZrO2 Mass Development

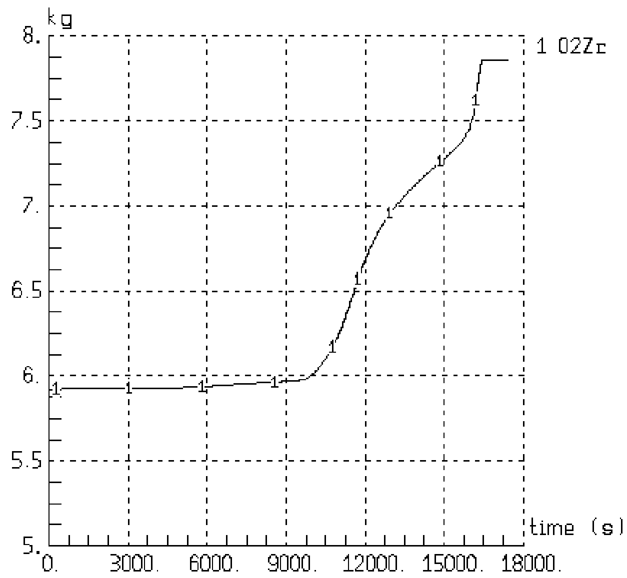
Zr mass in the core



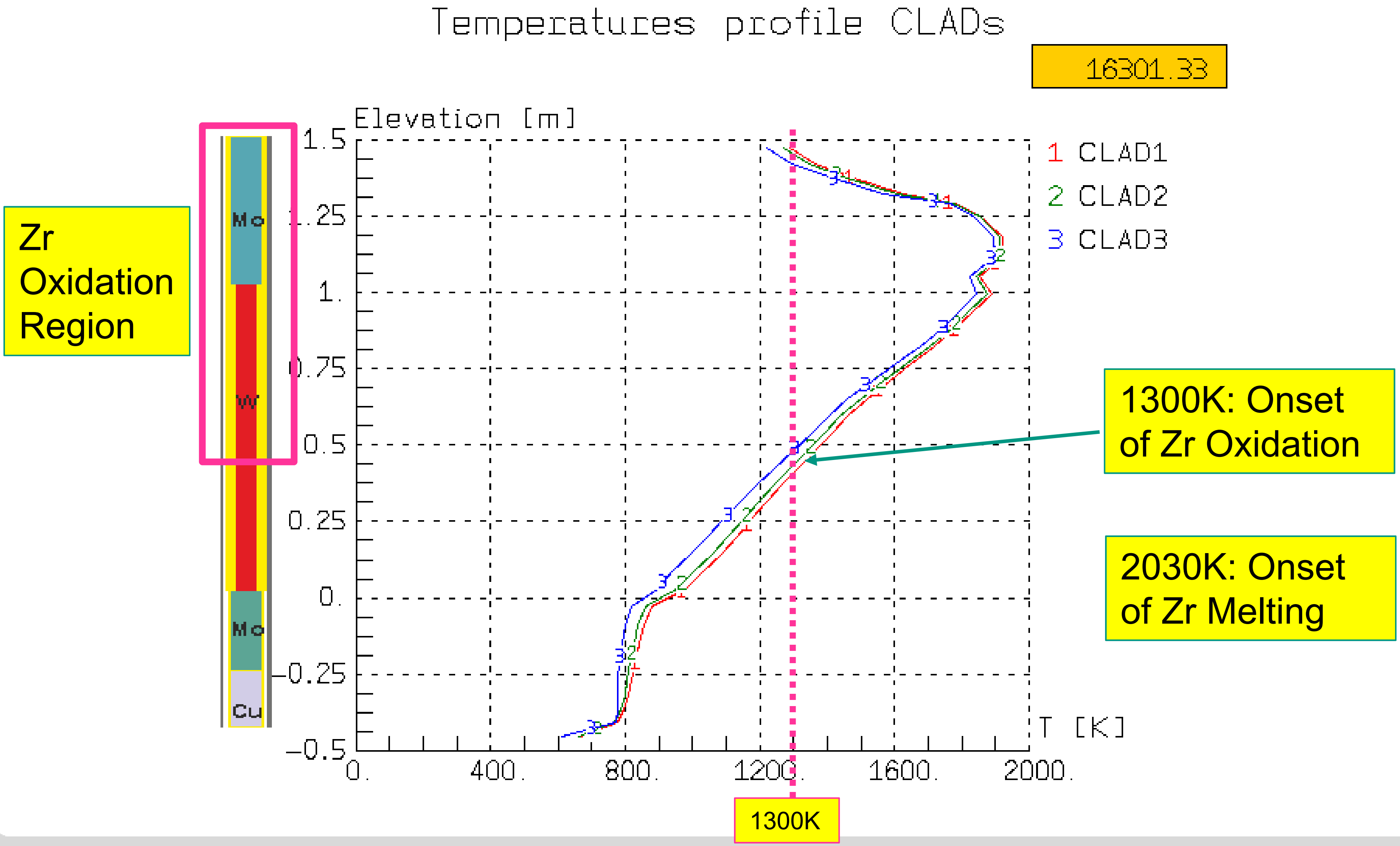
OZr mass in the core



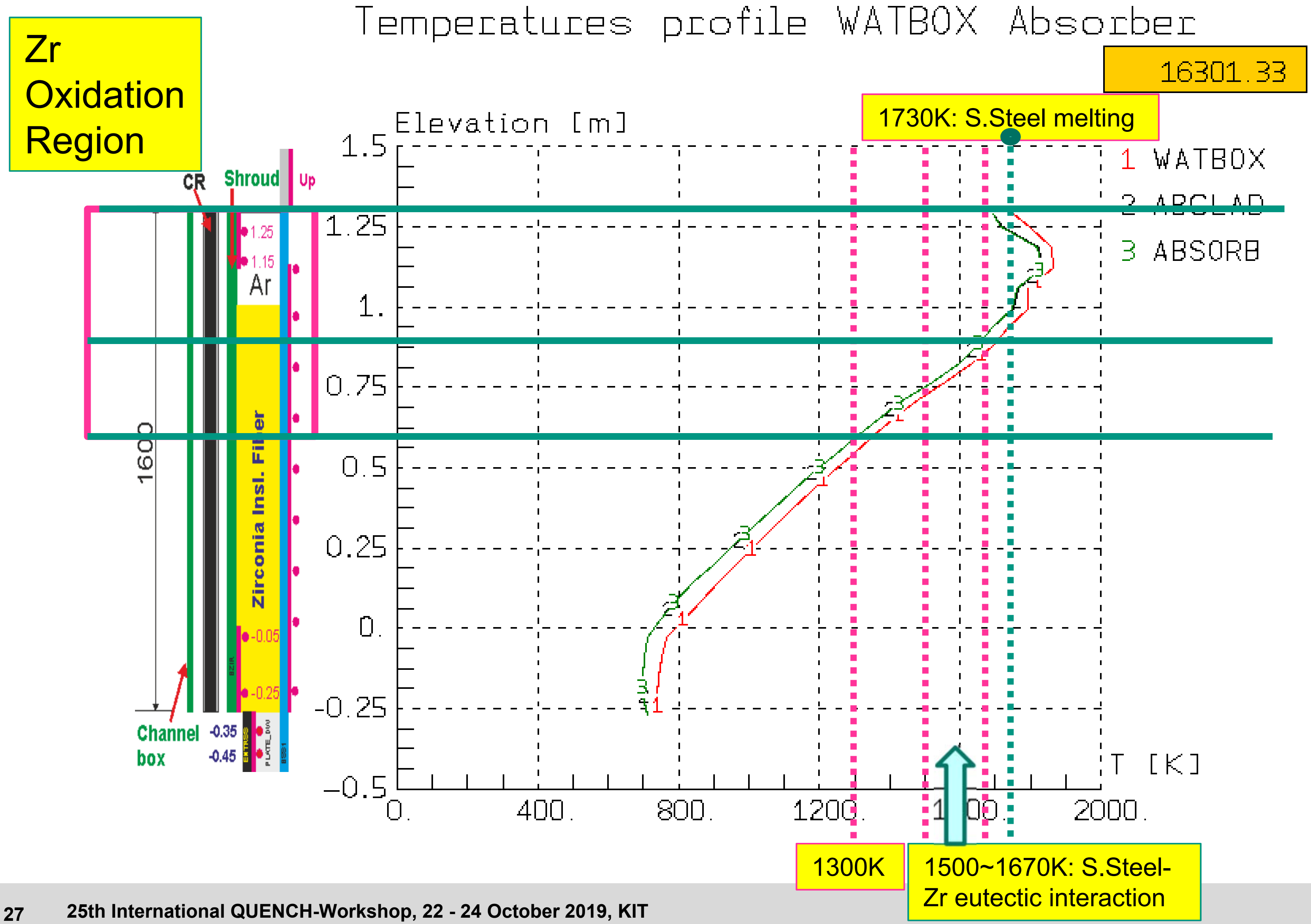
O2Zr mass in the core



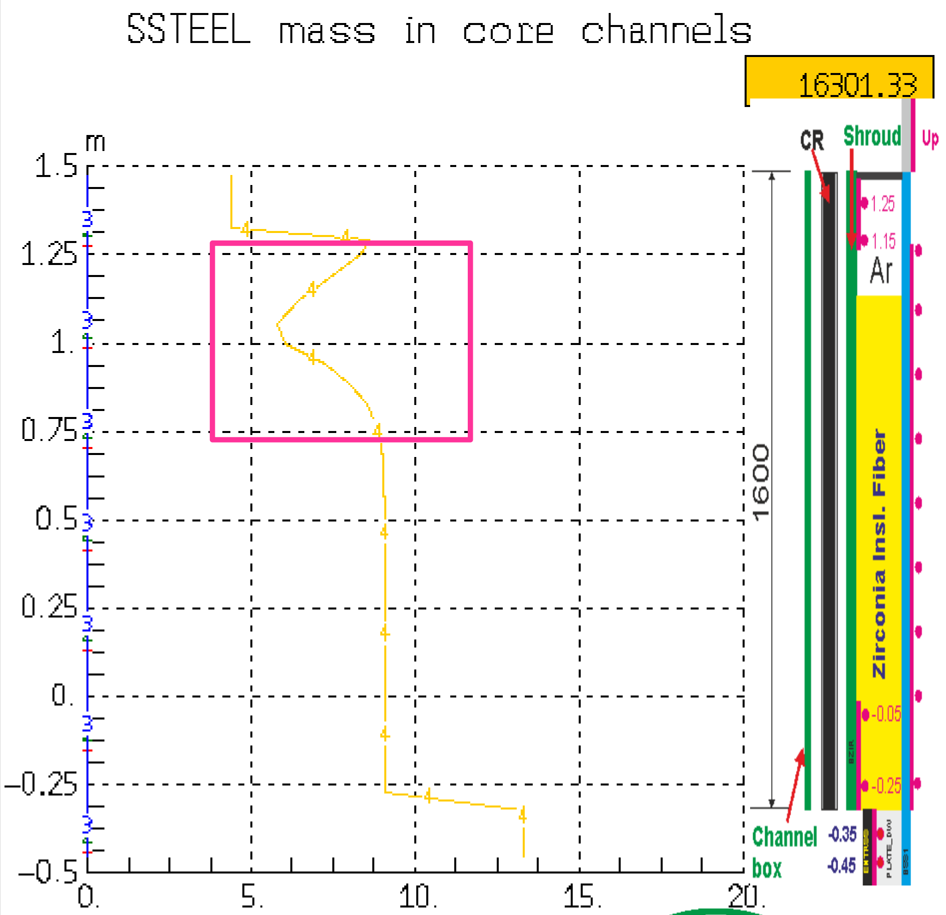
Cladding Temperature Profile at max Power Instant

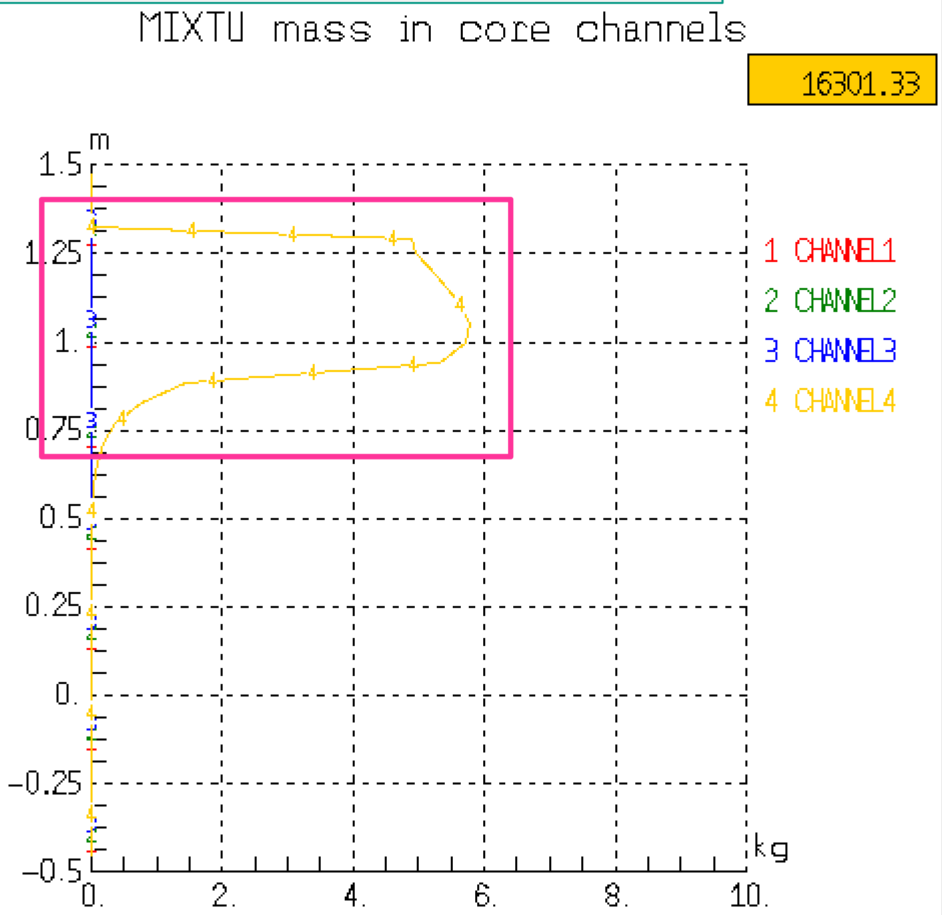


Channel Box, CR-cladding & CR Temperature Profile

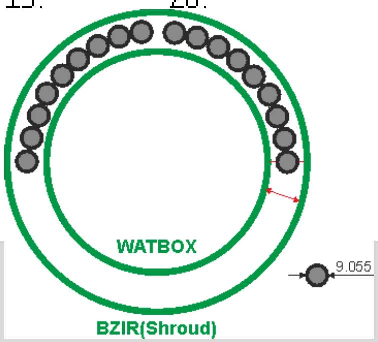


S.Steel & Mixture mass Axial Profile



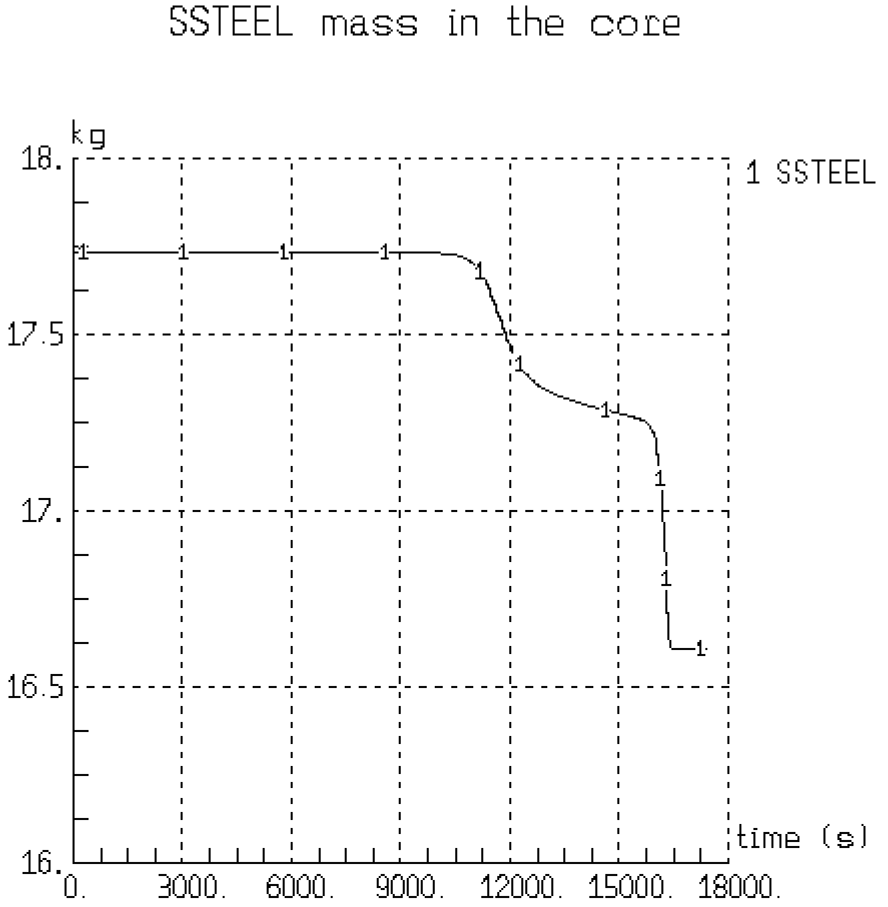


1730K S. Steel melting



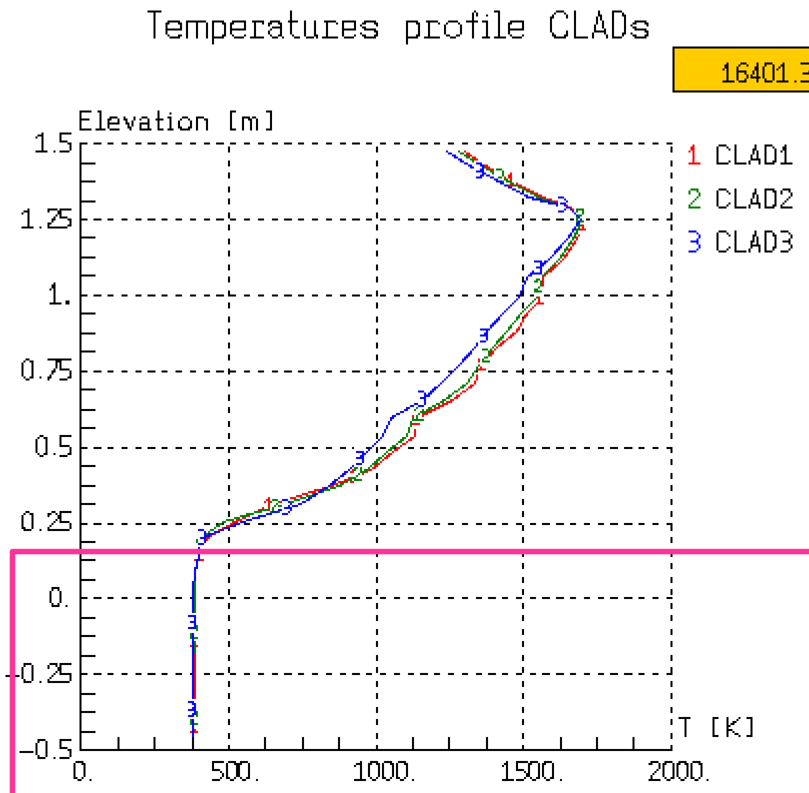
degraded materials:
(COMPACT or CRACKED) → (DISLOCAT).

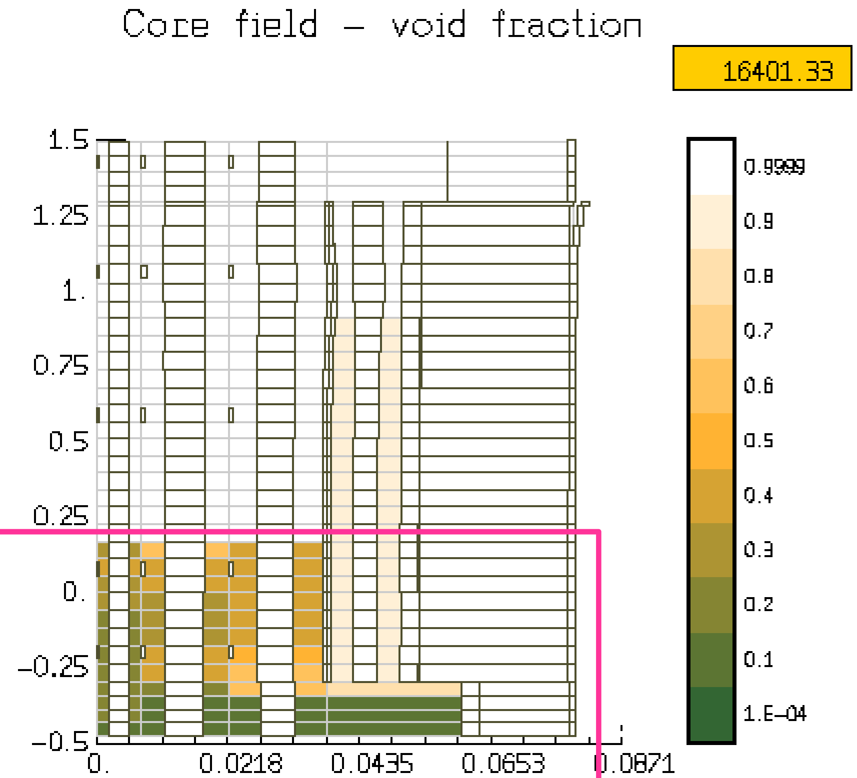
Total S.Steel mass Development



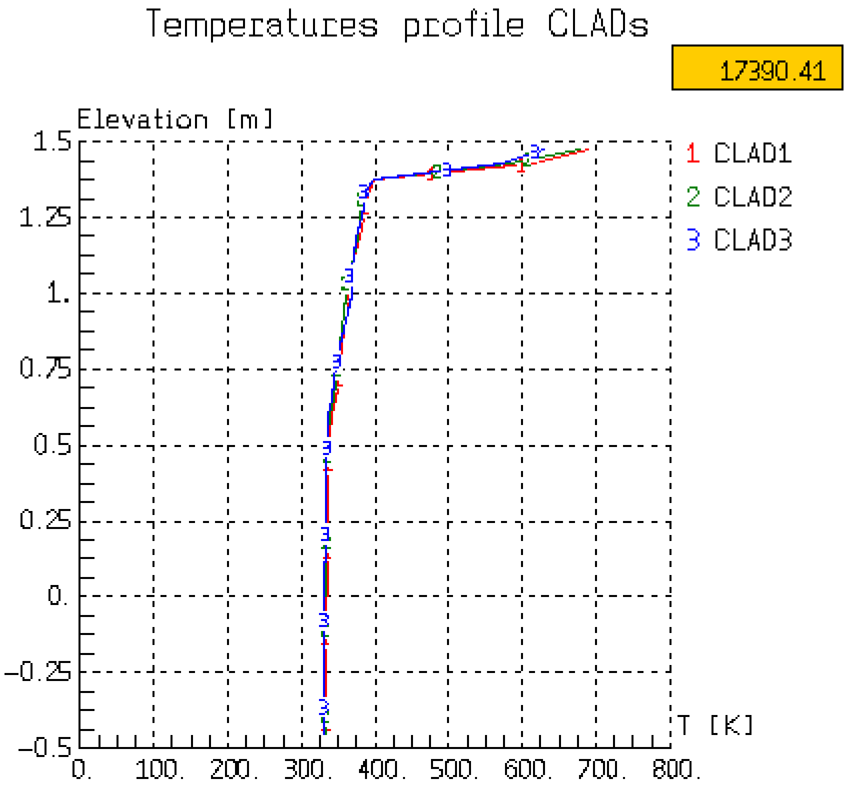
~ 1.5 Kg S. Steel melting

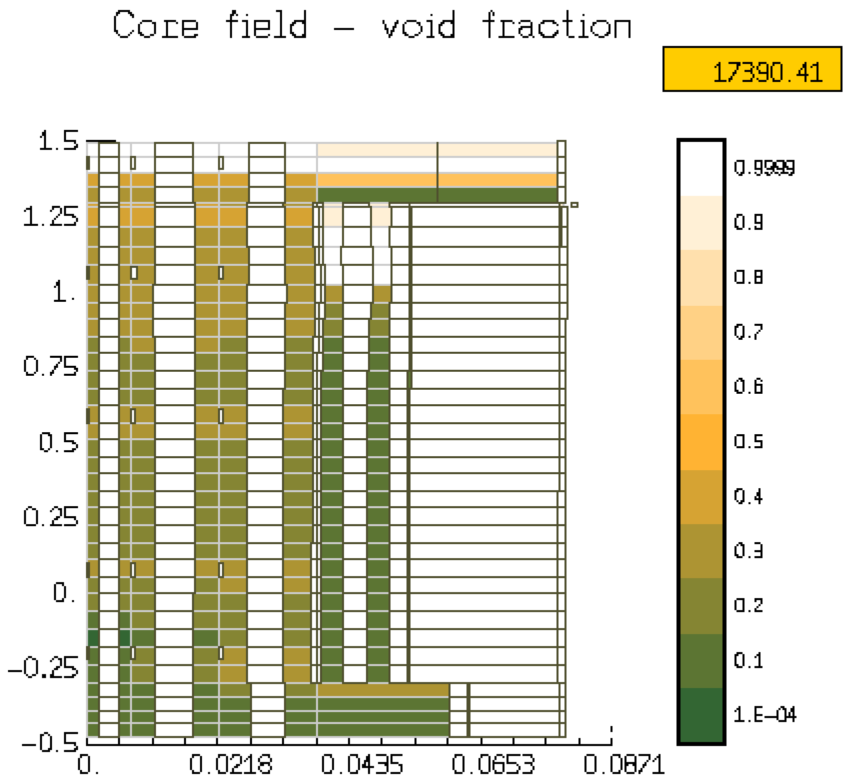
Quench Phase





Calculation End

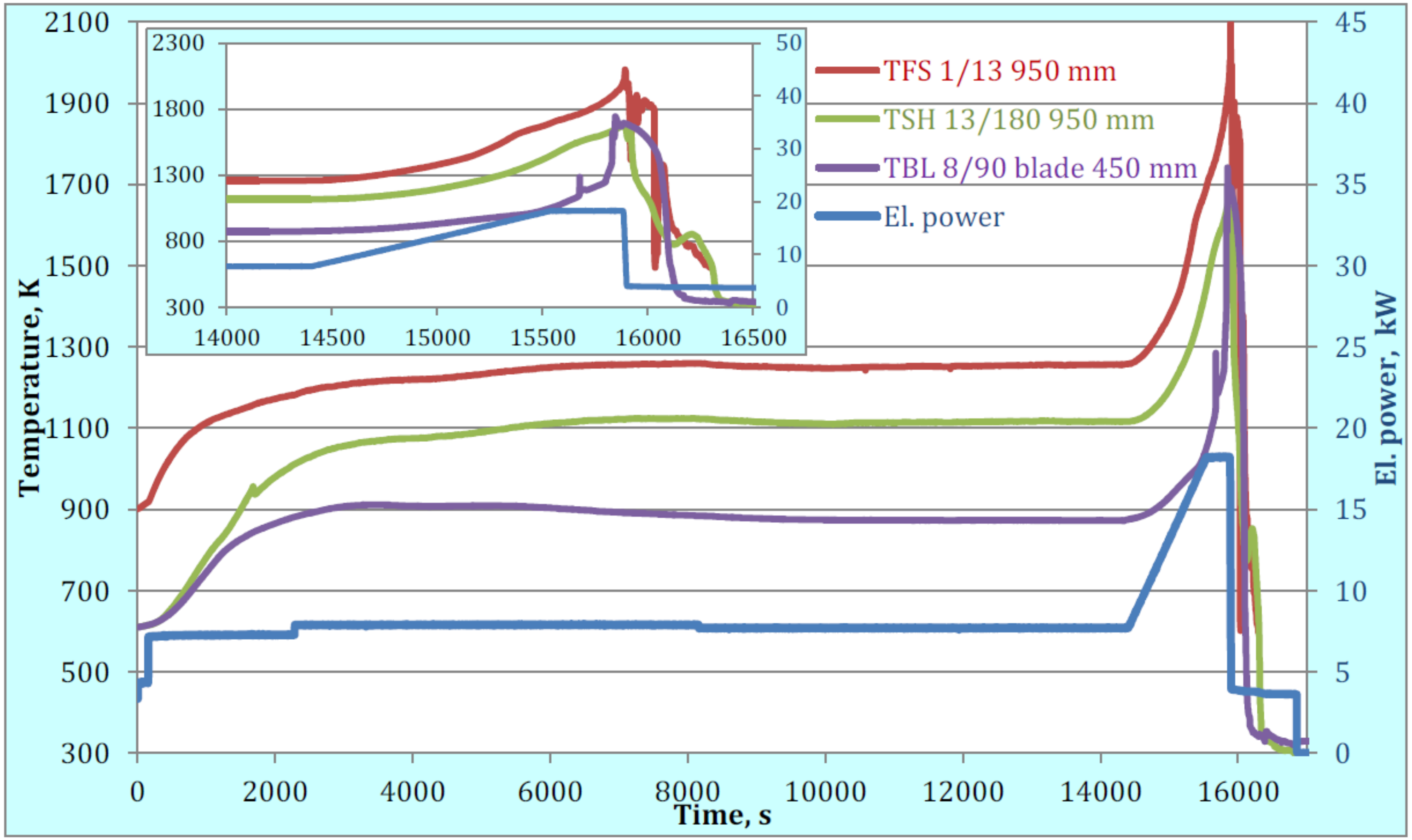




SUMMARY

- The present ASTEC version can be used to **simulate BWR bundle test**.
- In order to simulate the radiative heat exchanges between bundle rod and square channel box wall (e.g. Canister wall of BWR assembly), the square box should be modelled as **cylindrical geometry**.
- "**Cruciform control blade**": Present version can be applied for BWR case by modelling the **rectangular blade** as **equivalent cylinders**.
- The simulation results show ASTEC can give **reasonable results**. The results was used to support experimental staffs to design experiment progress.
- **OUTLOOK**: post-test calculations.

First information on QUENCH-20- bundle test



Electrical power profile during QUENCH-20 and readings of three selected thermocouples installed at cladding surface (TFS), shroud (TSH) (both at the hottest elevation of 950 mm) and at the absorber blade surface at the elevation of 450 mm.