Karlsruhe Institute of Technology

Analysis of QUENCH-20 Test with ASTEC V2.2.b

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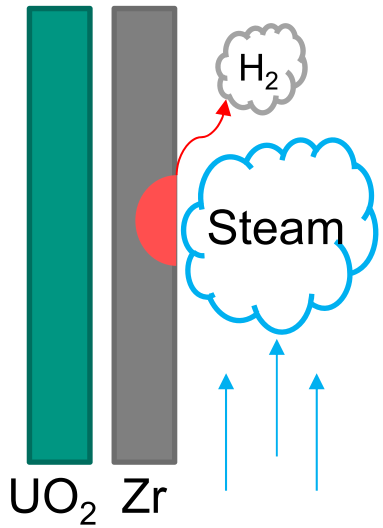
Introduction

- In case of long term LOCA in severe accident scenarios core uncovery occurs.
- Without heat removal capacity:
  - Heat-up in the core
  - Oxidation of metals by steam (more heat-up)
  - Hydrogen release by oxidation
  - Cladding deformation and loss of geometry
  - Fission product release
- Produced heat and degraded core leads corium and melt material corium threats:

  IN VESSEL and EX-VESSEL
- Released H2+Non-condensable gasses threats:

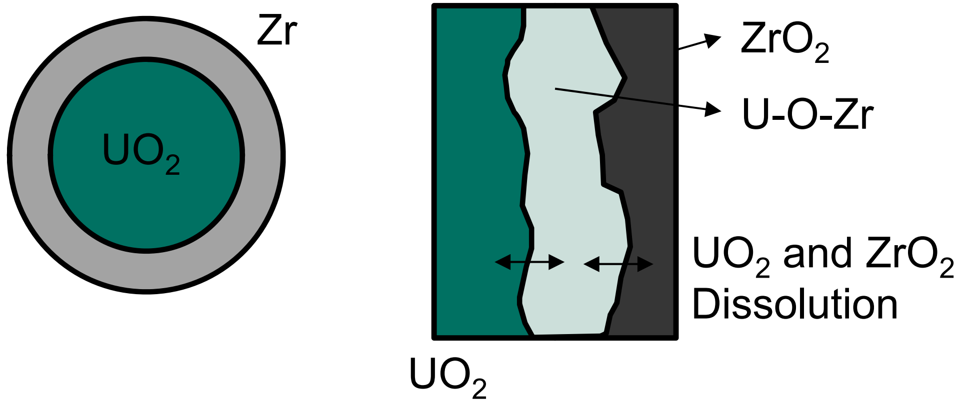
  EX-VESSEL

Prediction of in vessel phenomena is important for SAFETY

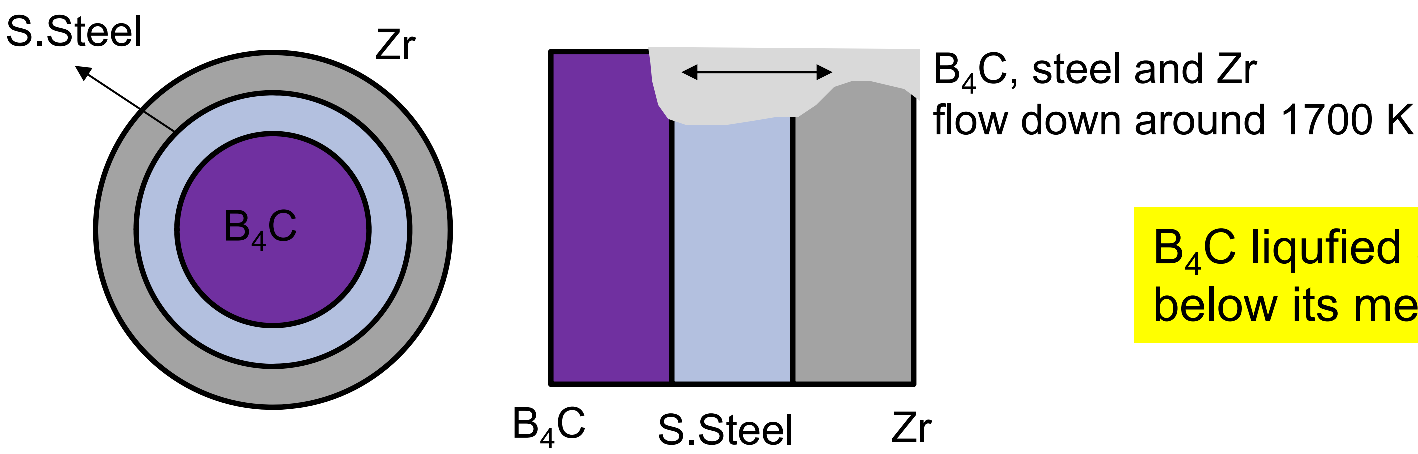


Introduction

- Not only oxidation process but also eutectic interactions are crucial for severe accident in vessel progression.



UO_2 liqufied 1000 K below its melting point



B_4C liqufied around 700 K below its melting point

Motivation

Are BWR type reactors different than PWRs?

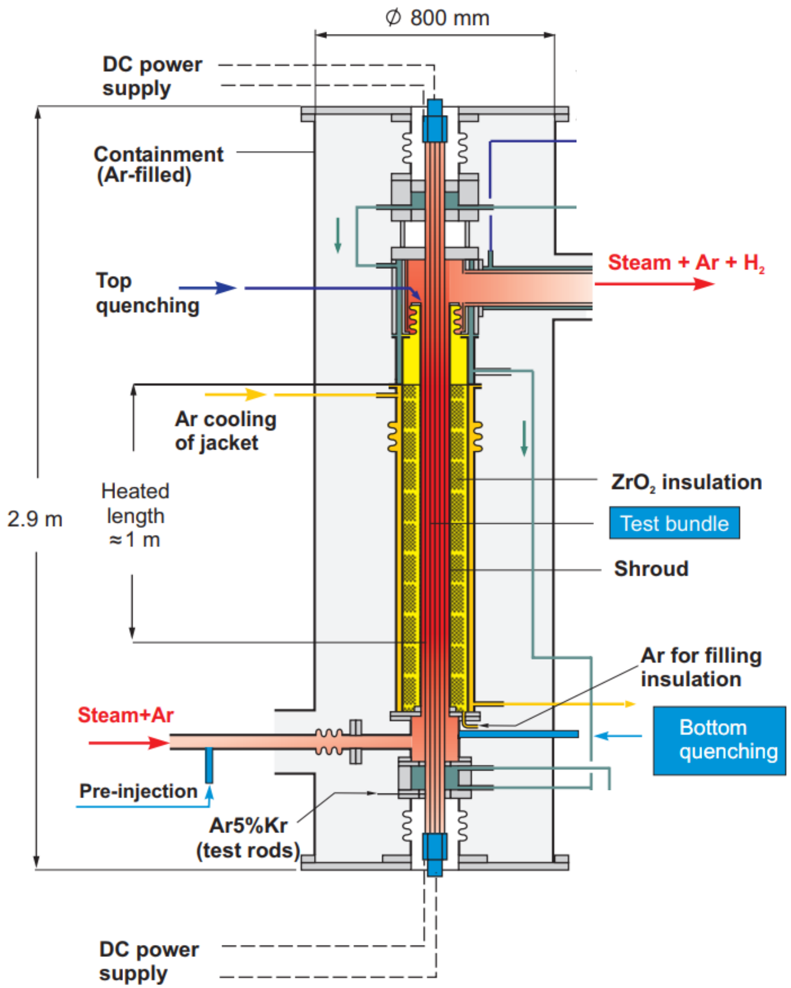
BWRs contains: More Zr (water channel boxes)
More Fe (absorber blades)
B_4C (absorber blades)

Oxidation → more Heat
more H_2

Chemical reaction	Energy release
$Zr + 2\,H_2O \rightarrow ZrO_2 + 2\,H_2$	$\Delta H = 6.4$ MJ/kg $_{Zr}$
$2\,Fe + 3\,H_2O \rightarrow Fe_2\,O_3 + 3\,H_2$	Not significant
$B_4C + 8\,H_2O \rightarrow 2\,B_2O_3 + CO_2 + 8\,H_2$	$\Delta H = 15$ MJ/kg $_{B4C}$

- Adequate models are necessary in order to predict the source terms during severe accident transients and improve severe accident management.
  - BWR Specific structures (Canister, absorber blades)
  - Eutectic interaction of BWR structures and their relocation models
  - Heat transfer models of BWR structures

QUENCH Test Facility



QUENCH Test Facility

In order to develop adequate models and validate severe accident codes for core degradation QUENCH experiments designed.

- Test facility enclosed and pressurized around 2 bar.
- Steam and Ar flow introduced from bottom and steam, Ar and hydrogen (produced from oxidation) flow upward outside of the bundle.

$$B_4C + 7H_2O(g) \leftrightarrow 2B_2O_3 + \boxed{CO(g)} + 7H_2(g)$$

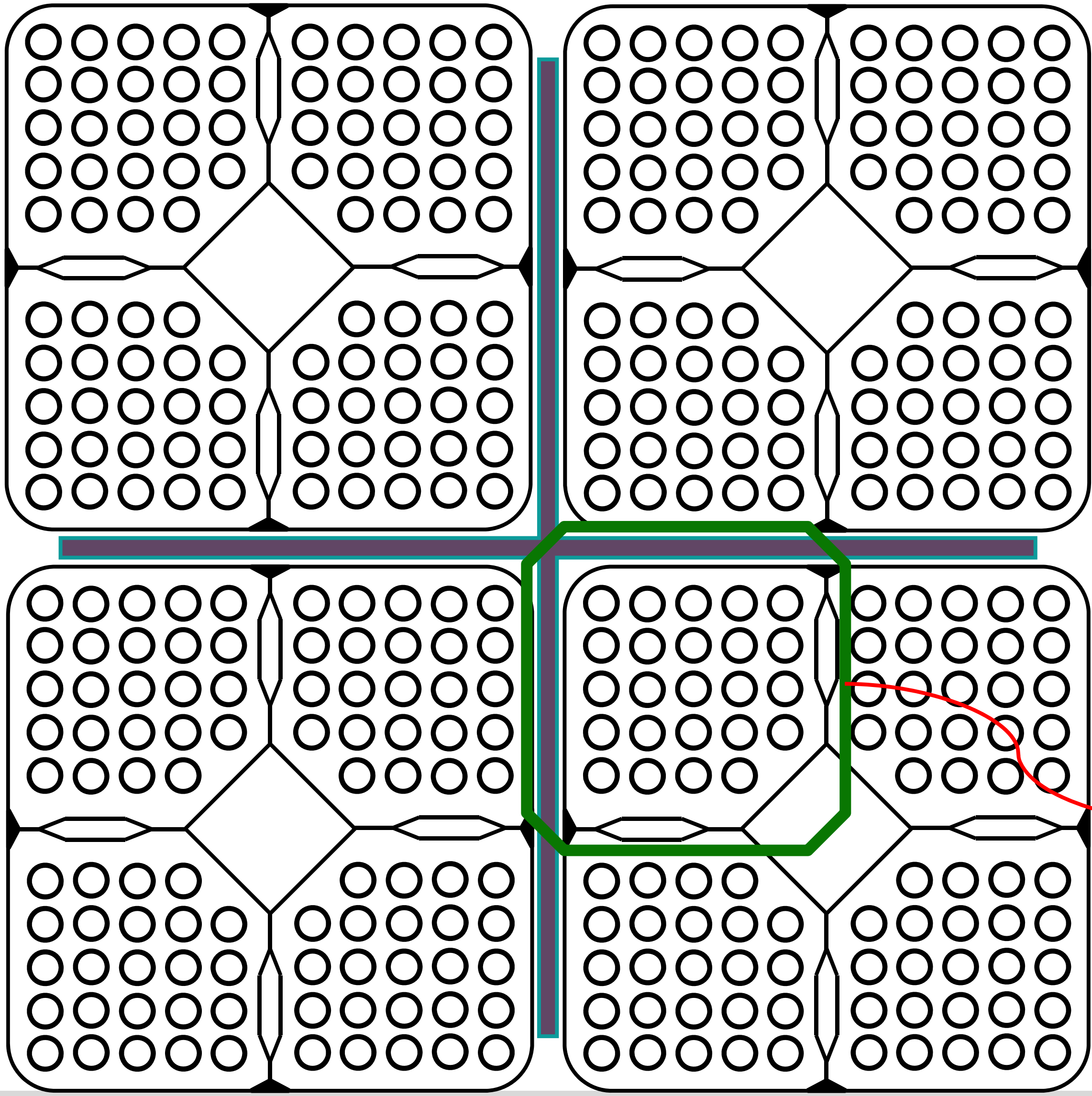
$$B_4C + 8H_2O(g) \leftrightarrow 2B_2O_3 + \boxed{CO_2(g)} + 8H_2(g)$$

$$B_4C + 6H_2O(g) \leftrightarrow 2B_2O_3 + \boxed{CH_4(g)} + 4H_2(g)$$

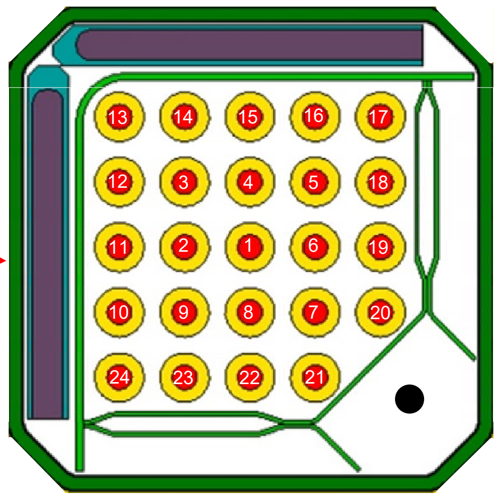
B_4C oxidation

- Quench water supplied from the bottom of the section with constant flow rate and temperature.
- Temperature control provided for bundle head and off-gas pipe in order to mitigate condensation in test section.

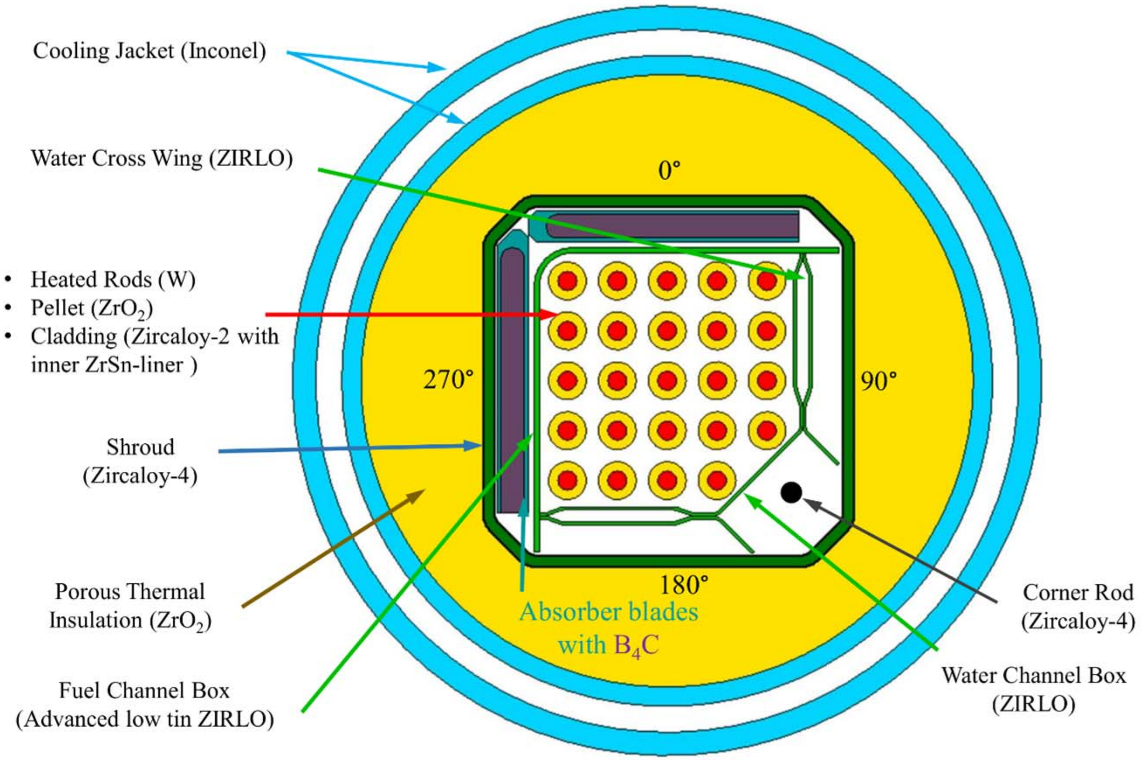
QUENCH-20 BWR Fuel Bundle (1/2)

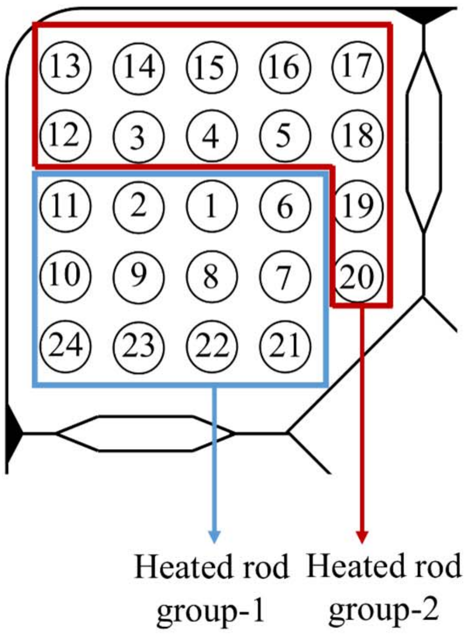


SVEA 96 OPTIMA-2
BWR Fuel Assembly



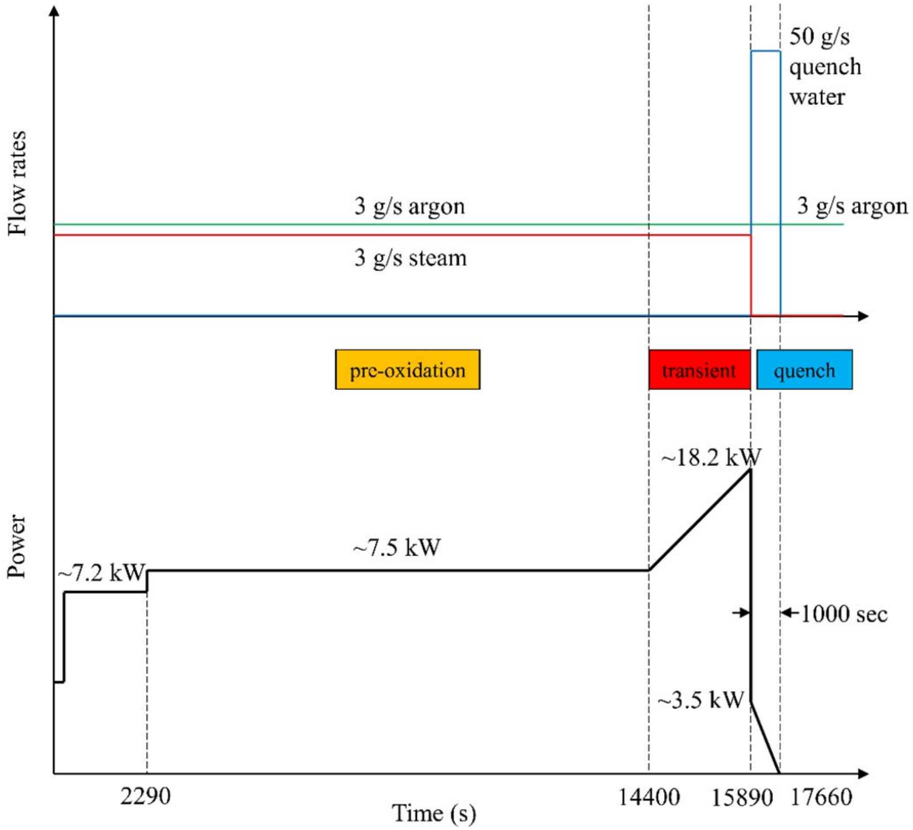
QUENCH-20 BWR Fuel Bundle (2/2)





QUENCH-20 Test Bundle Cross Section (1/4 SVEA 96 OPTIMA-2)

QUENCH-20 Test Transient

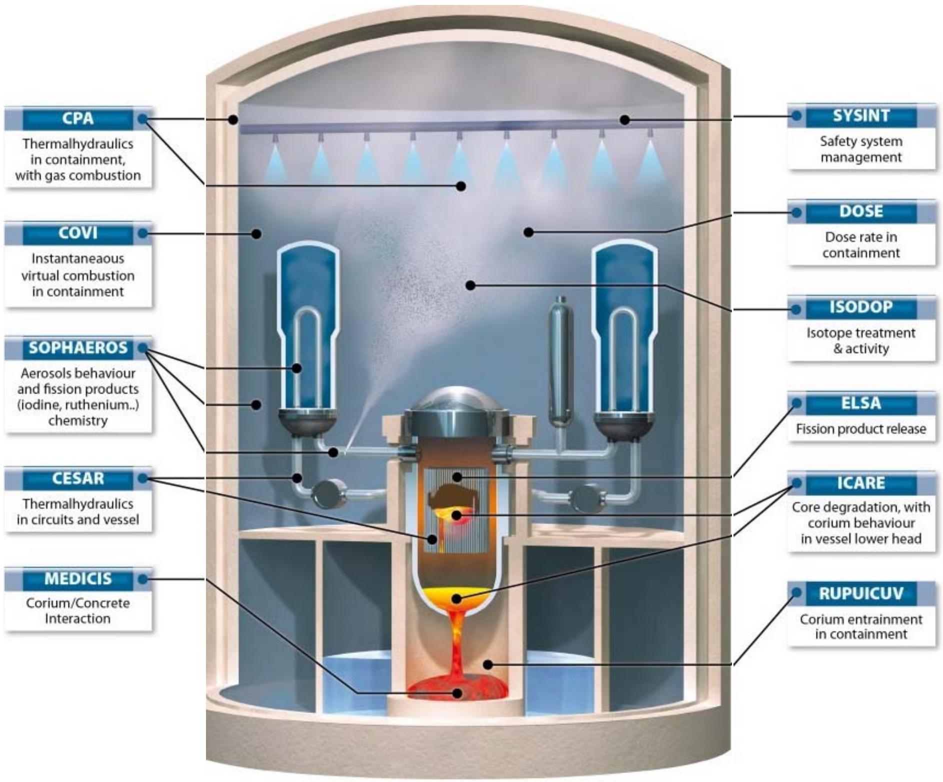


QUENCH-20 Test consist of three phases which are pre oxidation, transient and quench:

- **Pre-oxidation phase**: Superheated steam and Ar gasses (600-700 K) employed to the system from bottom. System pressure was 2 bar.
- **Transient phase**: Electric power increased. Steam and Ar flow maintained until quench phase.
- **Quench phase**: After transient case, 50 g/s quench water delivered to the bundle from bottom at room temperature.

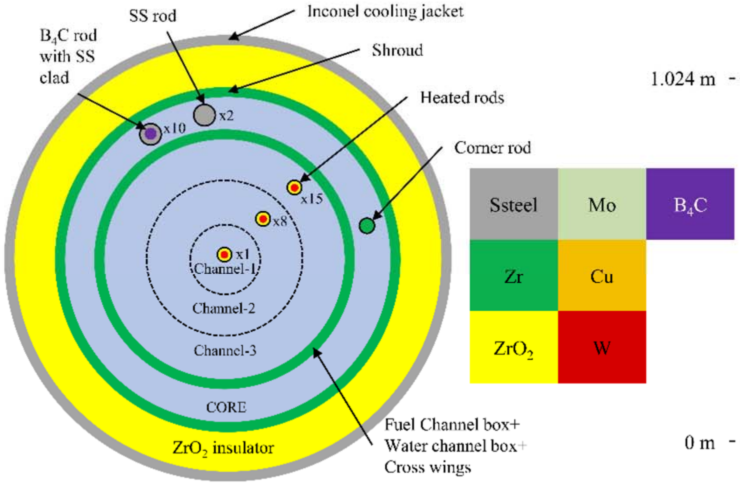
Numerical Tool: ASTEC Code

Accident Source Term Evaluation Code

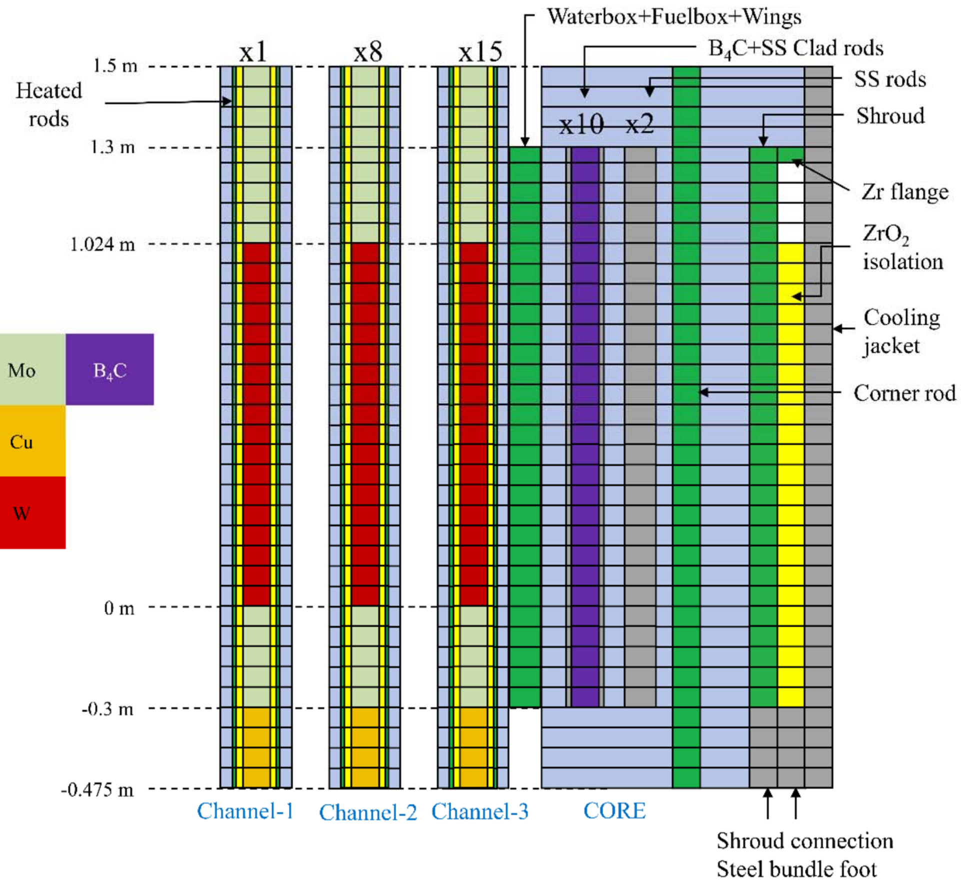


- European reference software for severe accidents.
- ASTEC simulates all sequences from initiating event to discharge of radioactive materials during core melt down accidents of LWRs.
- ASTEC has modular structure to implement physical models.
- Each module handles the part of the reactor and phenomena in there.

ASTEC Model of QUENCH-20 Fuel Bundle and Test Section

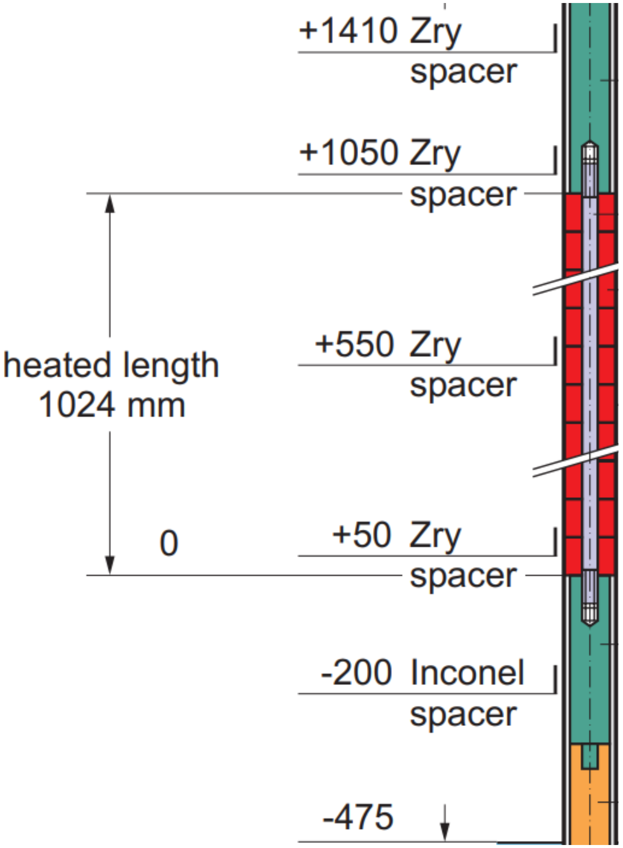


QUENCH-20 BWR bundle and test section ASTEC Model (Radial Representation)

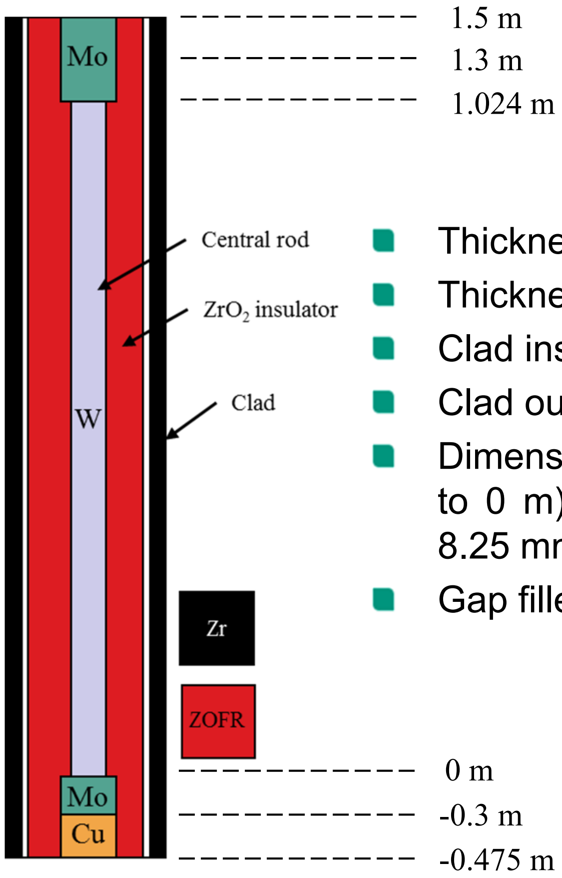


QUENCH-20 BWR bundle and test section ASTEC Model (Axial Representation)

ASTEC Model of QUENCH-20 Heated Rod



QUENCH-20 Heated Rod Composition



QUENCH-20 Heated Rod ASTEC Model

- Thickness of Mo and Cu = 7.85 mm
- Thickness of W = 5.25 mm
- Clad inside diameter = 8.63 mm
- Clad outside diameter = 9.84 mm
- Dimensions of ZrO2 = 8.25 mm (-0.475 to 0 m), 8.48 mm (0 to 1.024 m) and 8.25 mm (1.024 to 1.5 m)
- Gap filled with Kr (5 bar)

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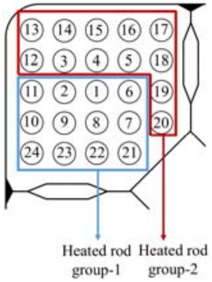
Boundary Conditions (1/2)

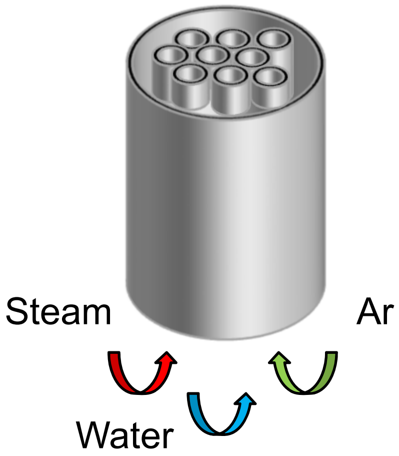
Described boundary conditions are employed according to QUENCH-20 test measurements:

- Electrical power generated for 24 heated rod one by one in the bundle by using test power output.



Electrical power is not same for Group-1 and Group-2 and rod distribution is not homogenous.

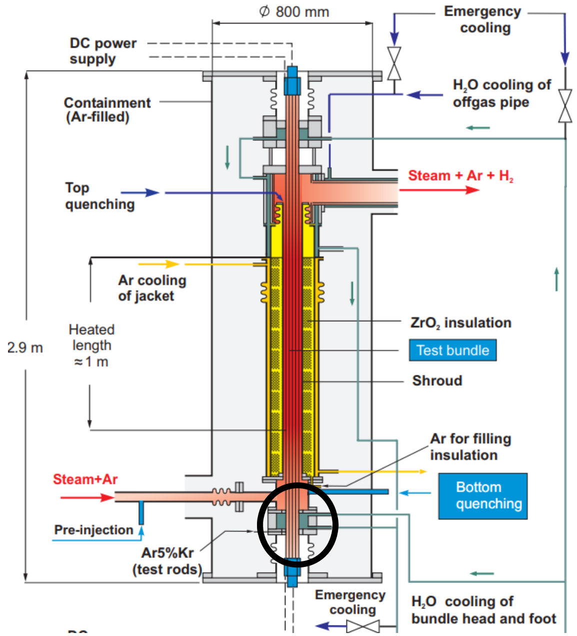
- Pressure boundary condition takes role at the top.
- Temperature and flow rate of steam and argon gasses at the inlet of the bundle introduced.
- Quench water temperature and flow rate takes action for quench phase.

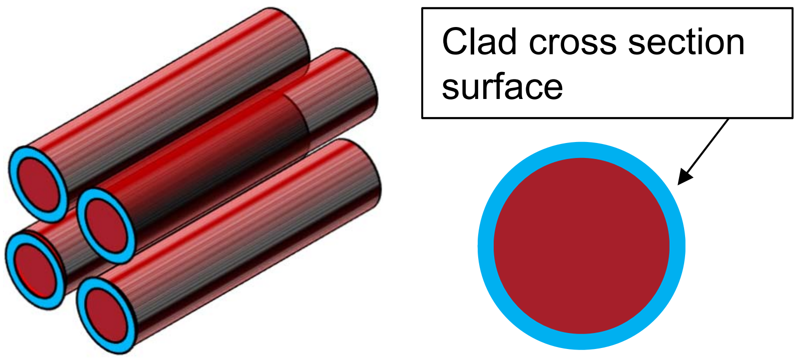


Boundary Conditions (2/2)

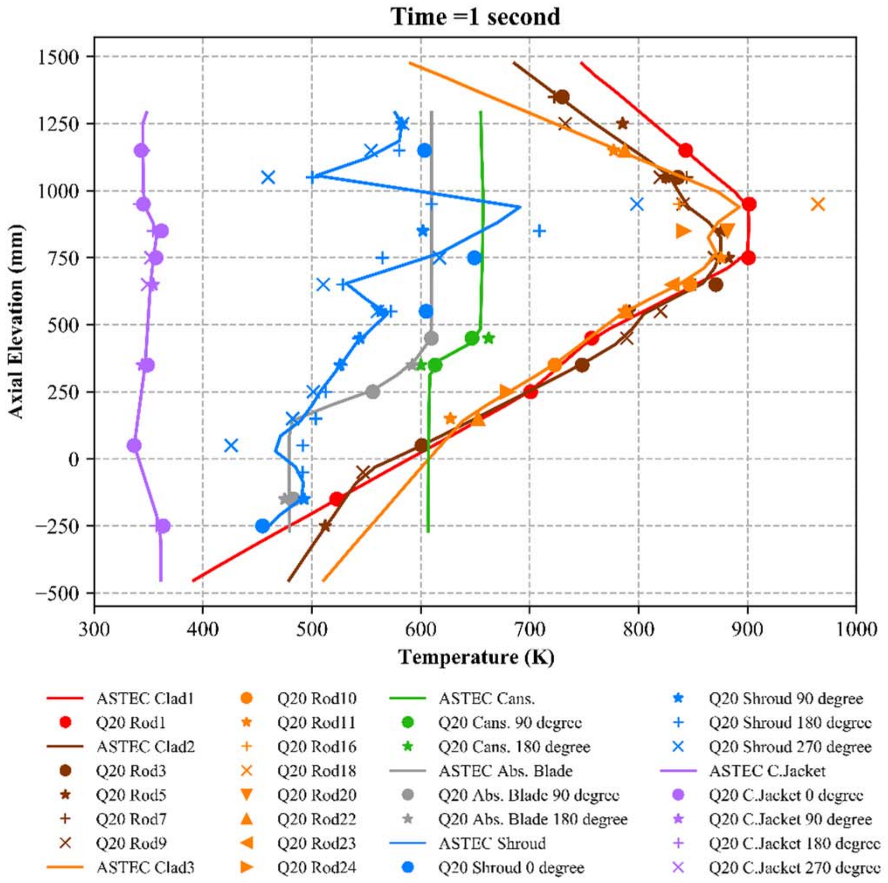
Described boundary conditions are employed according to QUENCH-20 test measurements:

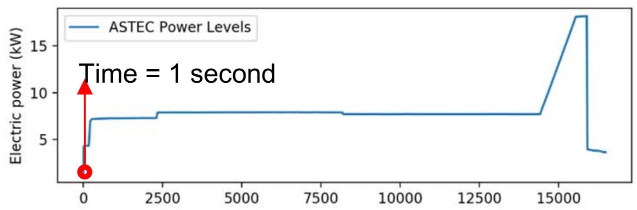
- Temperature of cooling jacket along the its height defined.
- Cooling water was defined for the bottom face of cladding material of heated rods.

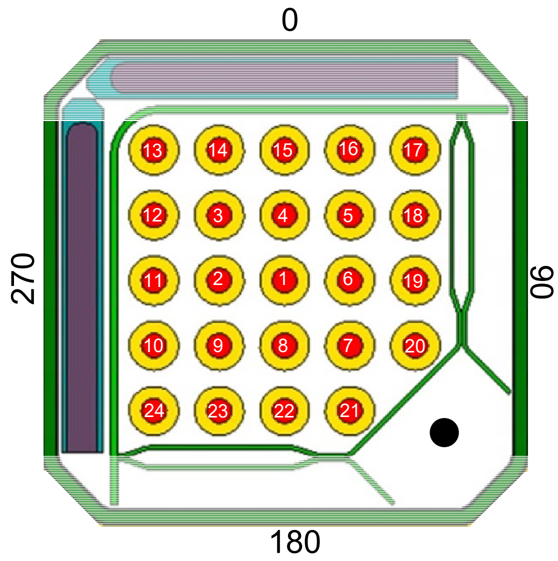




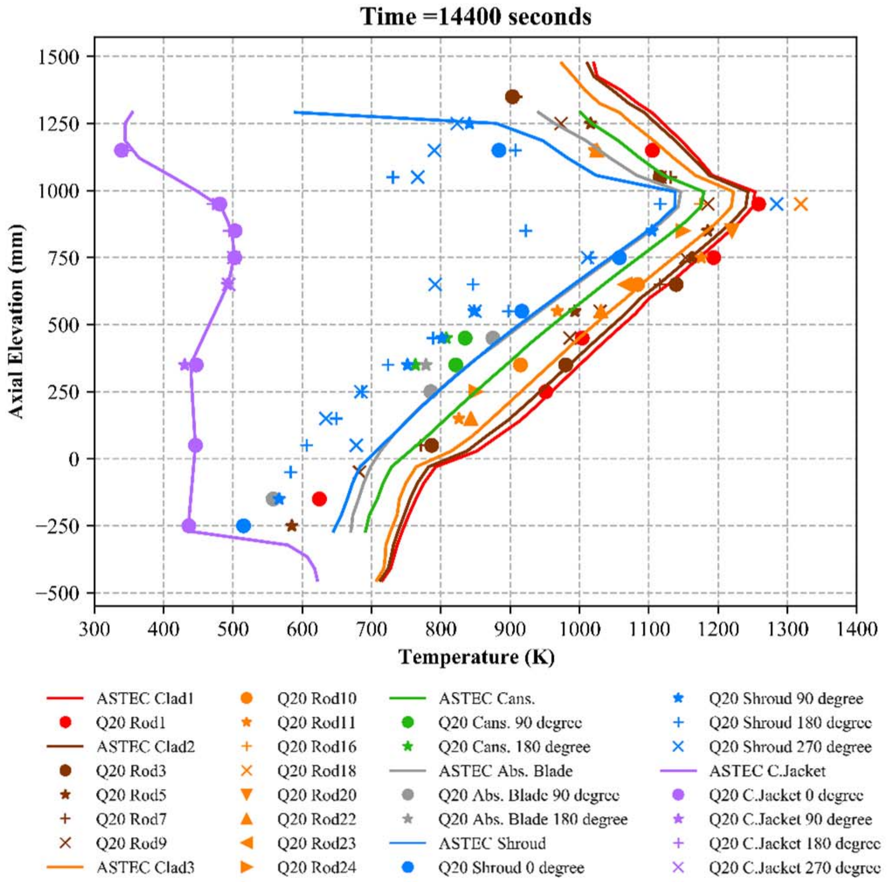
ASTEC Predictions of QUENCH-20 Test (1/5)

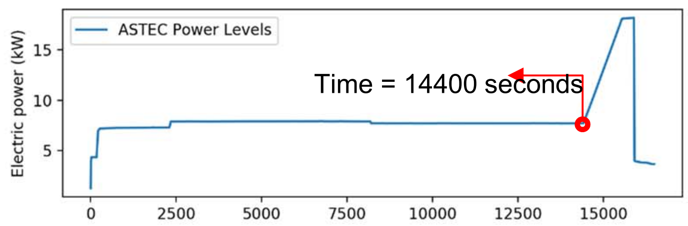


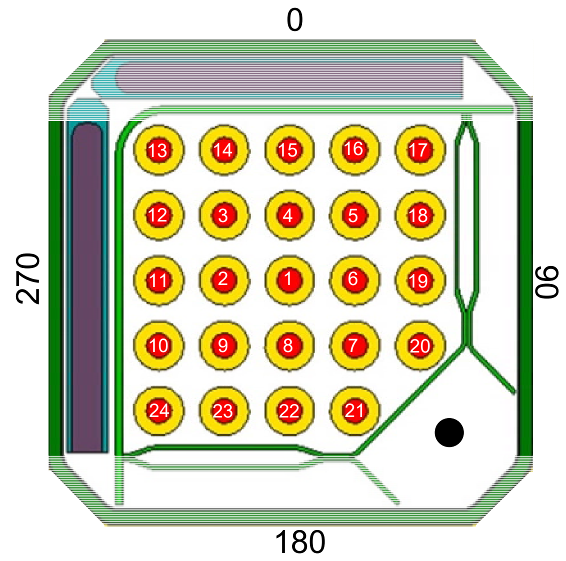




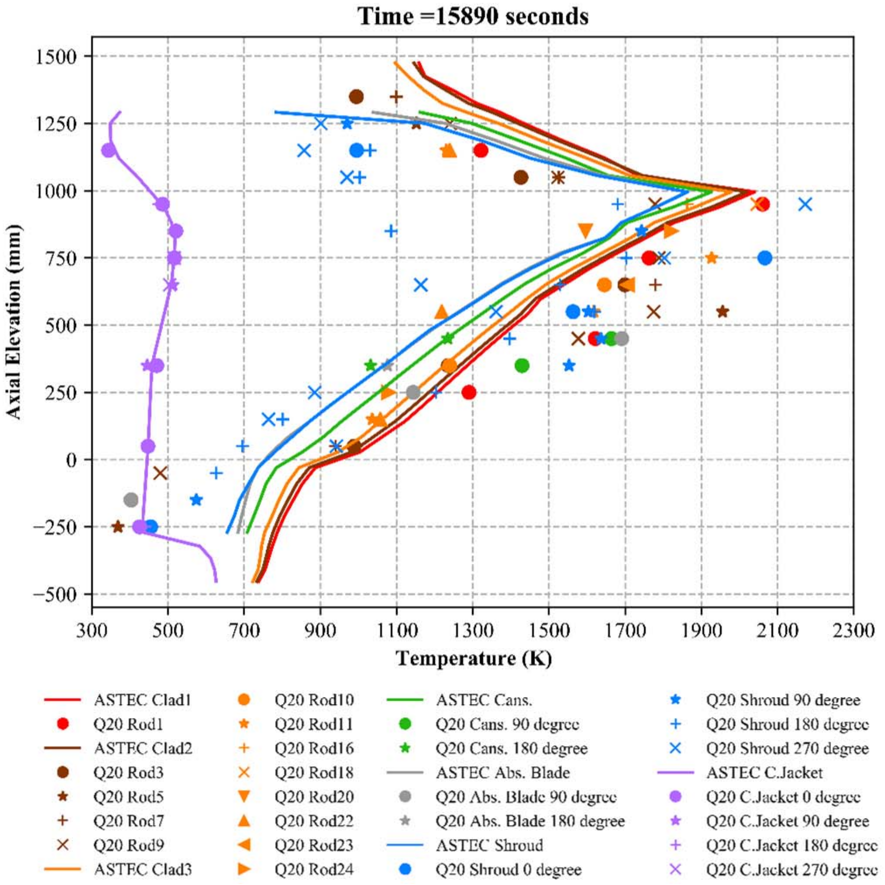
ASTEC Predictions of QUENCH-20 Test (2/5)

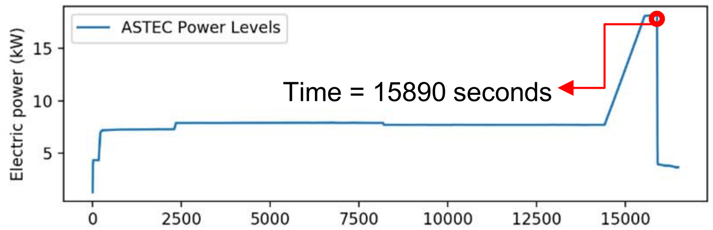


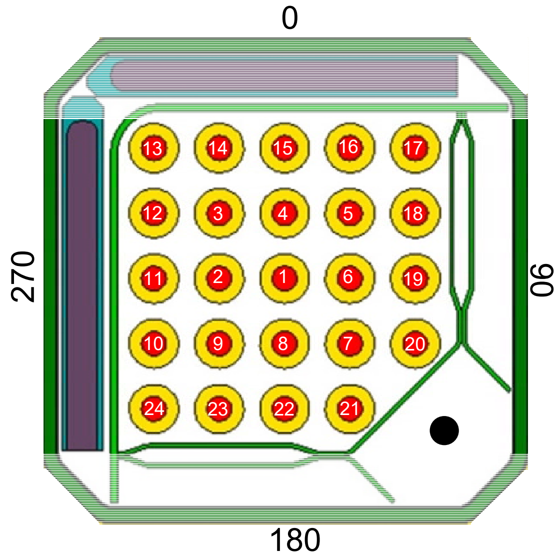




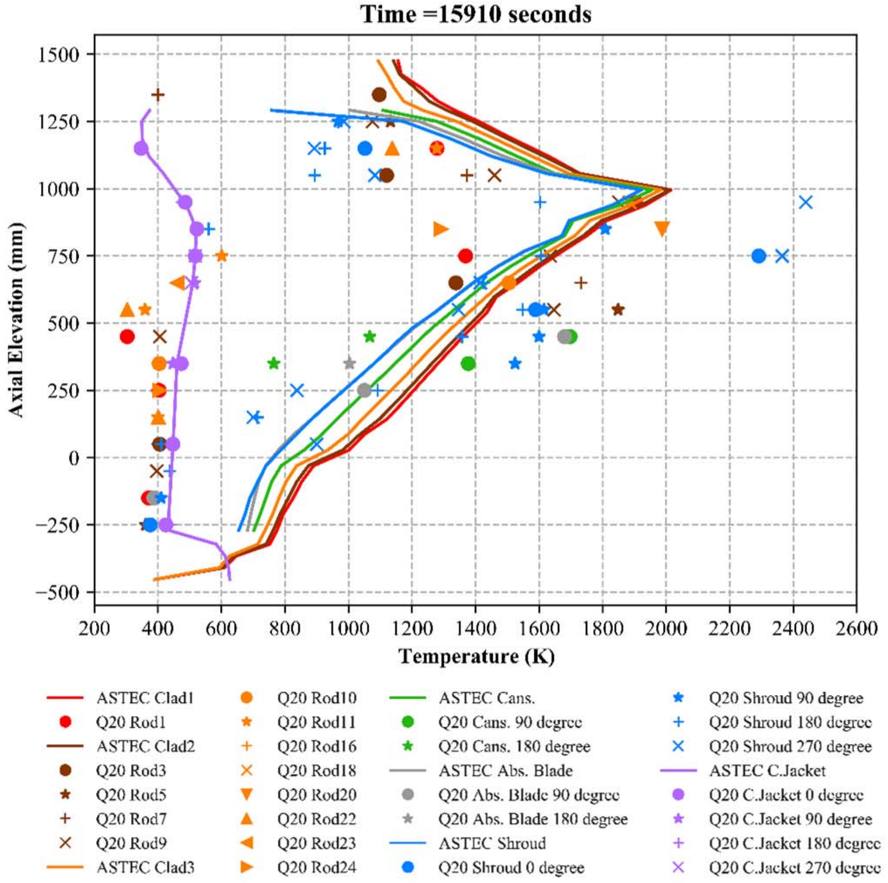
ASTEC Predictions of QUENCH-20 Test (3/5)

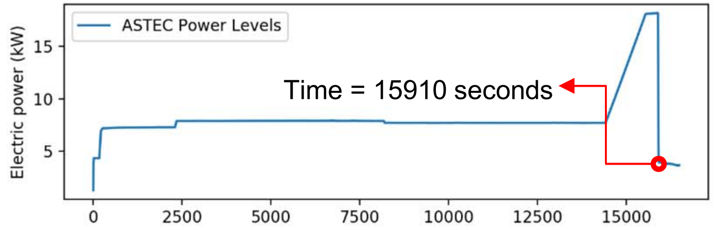


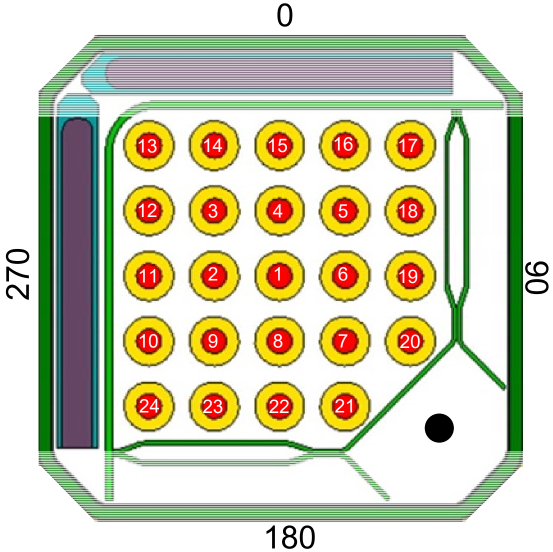




ASTEC Predictions of QUENCH-20 Test (4/5)







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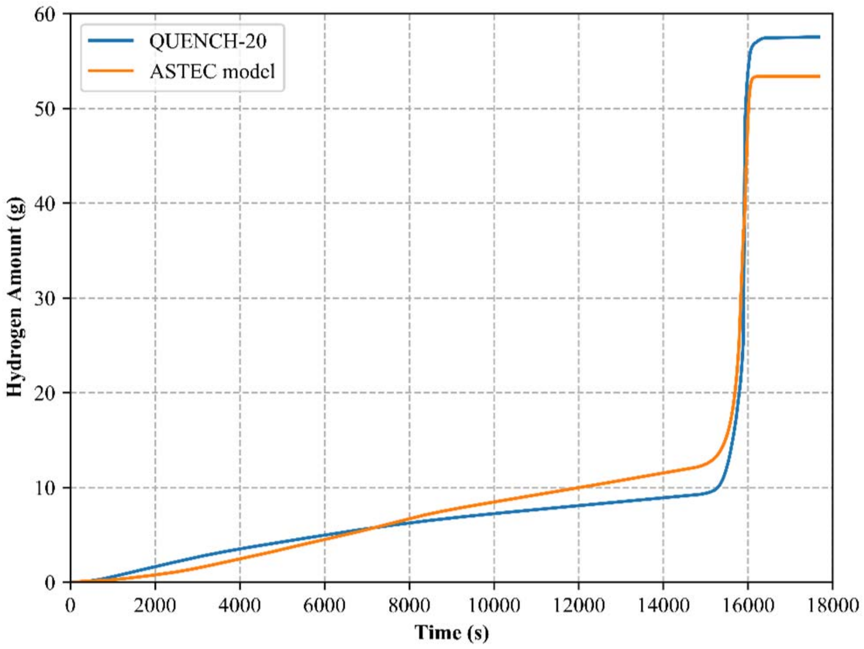
ASTEC Predictions of QUENCH-20 Test (5/5)



QUENCH-20 total H_2 amount = 57.4 g

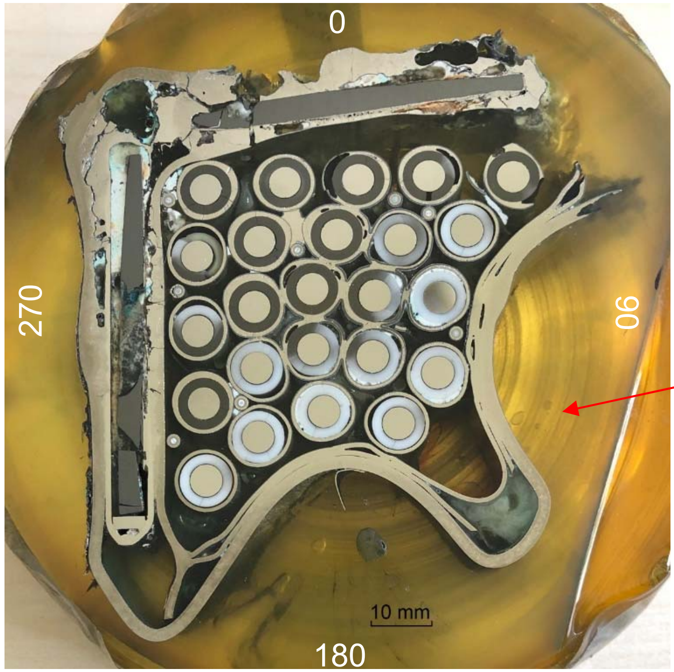
B_4C oxidation contribution = 10 g

ASTEC prediction total H_2 amount = 53.4 g

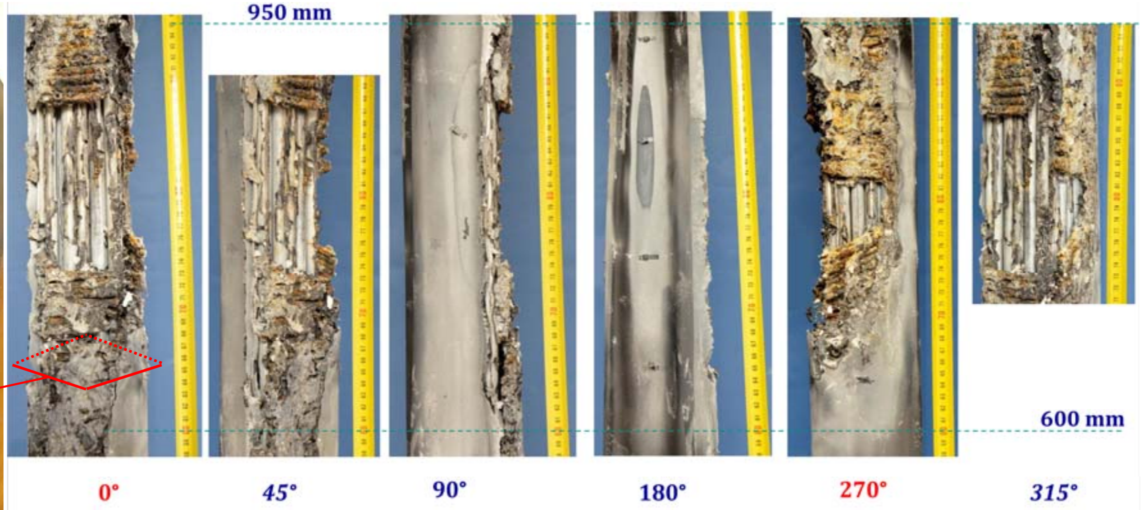
B_4C oxidation contribution = 9.48 g

Further detailed informations: Onur Murat, Victor Sanchez Espinoza, Shisheng Wang, Juri Stuckert, *Preliminary validation of ASTEC V2.2.b with QUENCH-20 BWR bundle experiment*, Nuclear Engineering and Design 370 (2020)

QUENCH-20 Post Test Pictures



QUENCH-20 Bundle Post Test Cross Section (Height = 650 mm)



ASTEC did not predict strong degradation and failure of shroud

Conclusion

- Considering the geometrical modeling pecularities axial temperature of structures are in acceptable manner.
- Total amount of hydrogen generation, including B4C oxidation, are in good agreement with test readings.
- Shroud failure was not observed in the ASTEC model.
  - Inhomogenity of structural placement in the test section and eutectic interactions which based on the how close the metallic structures are reason for that.
- Correct geometrical representation and placement of Blades (Slab) and Fuel Channel Box (Rectangular) are necessary.
  - There was no radiative heat transfer model for reactangular fuel boxes for version V2.2.b.
  - Definition of absorber material inside slab blades are not possible, which means no eutectic interaction, no material relocation due to eutectic interactions.