Analysis of the QUENCH-14 bundle experiment using ASTECv2.0R2p2

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Introduction

- The aim is to present results in the modeling of QUENCH-14 using ASTEC. Both Techn. Univ. Sofia and KIT test the applicability of ASTEC for modeling QUENCH experiments.
- QUENCH experiments investigate the H_2 source term resulting from the water injection into an uncovered core of LWR as well as the high temperature behavior of core materials under transient conditions.

QUENCH-14 experiment

The QUENCH-14 experiment investigated the effect of M5® cladding material on bundle oxidation and core reflooding, in comparison with the tests QUENCH-06 that used Zry-4. The bundle configuration of QUENCH-14 with 1 unheated rod, 20 heated rods, and 4 corner rods was otherwise identical to QUENCH-06.

The test was conducted in principle with the same protocol as QUENCH-06, so that the effects of the change of cladding material could be observed more easily.

QUENCH-14 experiment

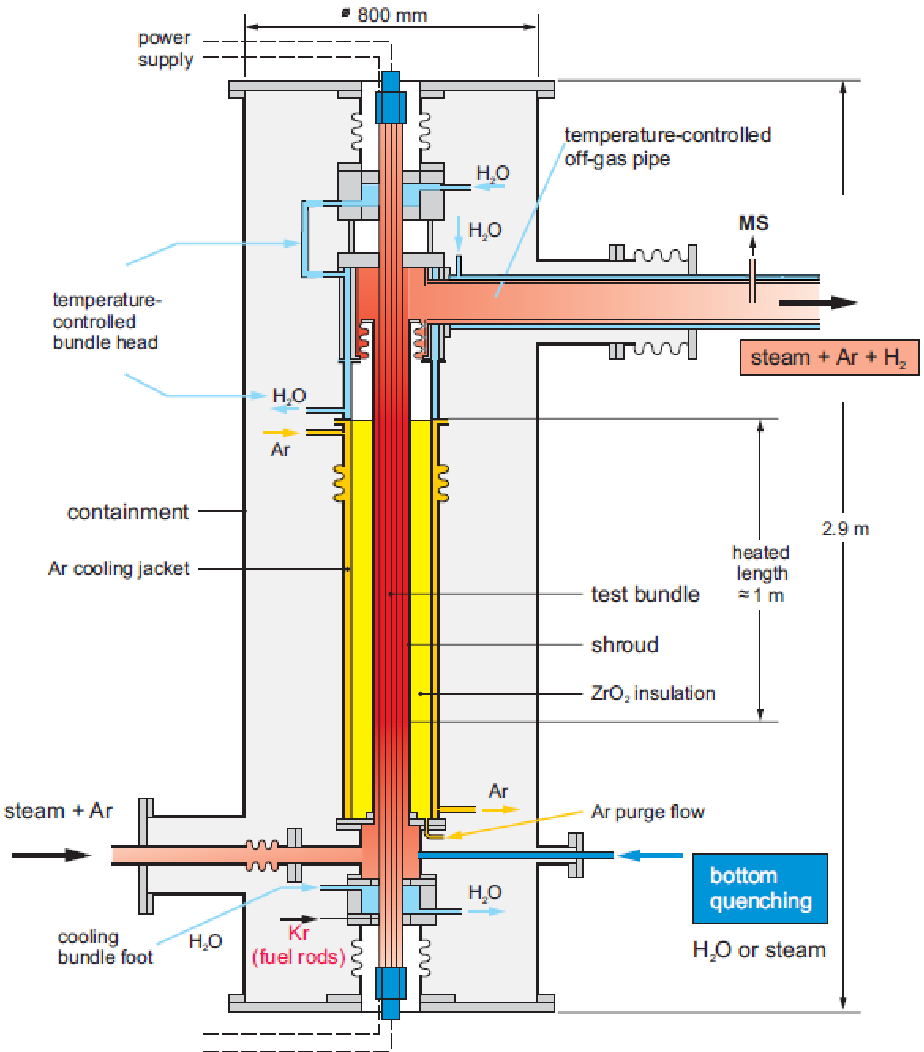

Fig.1 QUENCH-14 Test section

The test section is enclosed by a safety containment. Superheated steam from the SG and super heater together with Ar enter test bundle at the bottom. Ar, steam and H2 produced in the Zr-H2O(g) reaction flow upwards inside the bundle and from the outlet at the top through a water-cooled off-gas pipe to the condenser, where the remaining steam is separated from the non-condensable gases Ar and H2.

QUENCH-14 experiment

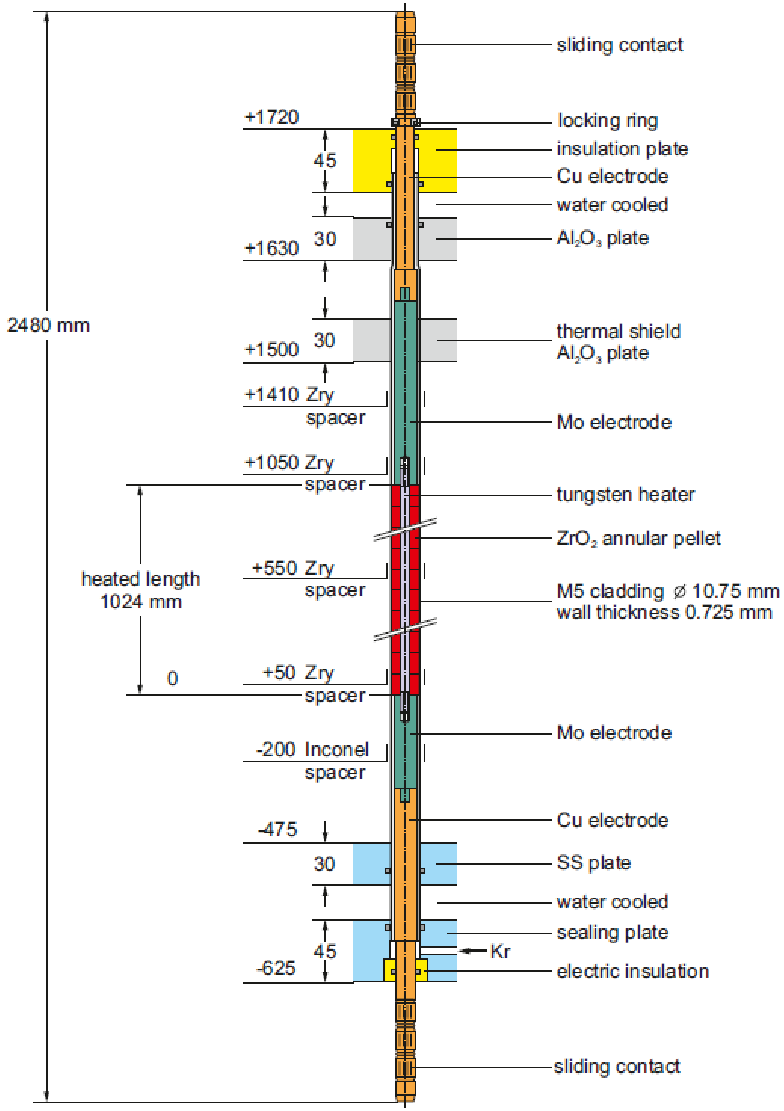

Fig.2 Fuel rod simulator

The test bundle is made up of 21 fuel rod simulators and of 4 corner rods. The fuel rod simulators are held in their positions by 5 grid spacers, 4 of Zry-4, and one of Inconel 718 in the lower bundle zone.

The rod cladding of the heated and unheated fuel rod simulator is M5® (industrial product AREVA)

The total heating power is 70 kW. About 40 % of the power is released into the inner rod circuit (8 fuel rod simulators); 60 % in the outer rod circuit (12 fuel rod simulators).

The test bundle is surrounded by a 3.25 mm thick shroud (80 mm ID) made of Zry-4 with a 37 mm thick ZrO_2 fiber insulation and an annular cooling jacket made of Inconel 600 (inner tube) and SS (outer tube).

QUENCH-14 experiment

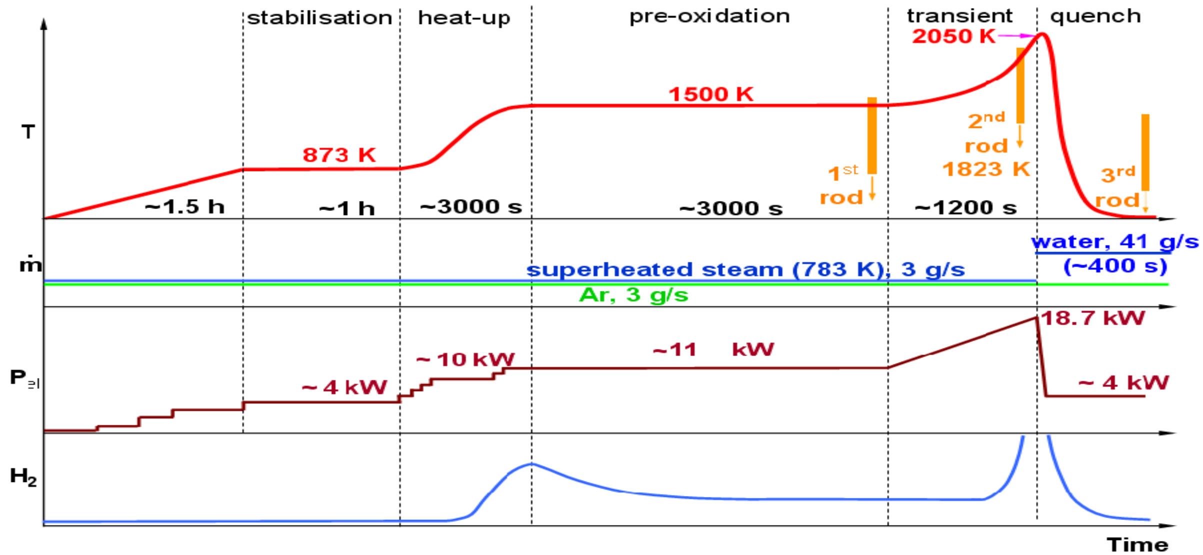

Fig.3 QUENCH-14 test phases

The QUENCH-14 test phases were as follows:

Heatup to ~873 K. Facility check.

Phase I Stabilization at ~873 K.

Phase II Heat-up with ~0.3-0.6 K/s to ~1500 K.

Phase III Pre-ox of the test bundle in a flow of 3 g/s of superheated steam and 3 g/s argon for ~3000 s at relatively constant peak temperature of ~1500 K. Withdrawal of corner rod B at the end.

Phase IV Transient heat-up with 0.3...2.0 K/s from ~1500 to ~2050 K in a flow of 3 g/s of superheated steam and 3 g/s argon. Withdrawal of corner rod D ~30 s before quench initiation.

Phase V Quenching of the bundle by a flow of ~41 g/s of water.

QUENCH-14 input deck adaptation

for modeling QUENCH-14 an existing QUENCH-06 ID was used developed by IRSN for ASTECv1.3R2.

To adapt the input deck of QUENCH-06 to the conditions of ASTECv2.0R2p2:

- QUENCH-06 ID is adapted to the style of ICARE module (part of ASTECv2.0R2p2).

To adapt the input deck of QUENCH-06 to conditions of QUENCH-14:

- for temp. range (1073–1673)K, the M5® oxidation kinetics obtained by measurement at KIT is taken into account . For temp range (1674- 2050 K) were used the existing data for Zry-4 were adopted instead of the corresponding –missing- M5® values
- El. power of two circuits of heating rods are changed in accordance to experimental results.
- The experimental data for temp-s are changed as they were presented for exp. data for three types of rods – central, one from the internal group and one from the outer group.
- The exp. data points for H_2 production were changed according to experimental results from Q-6 to -14
- Visualization-3 functions are added into the QUENCH-14 ID : the rate of H_2 prod.[kg/s]; cladding layer thickness evolution vs. time and cladding layer thickness in function of elevation /thanks to S. Bertusi

Results by ASTECv2.0R2p2

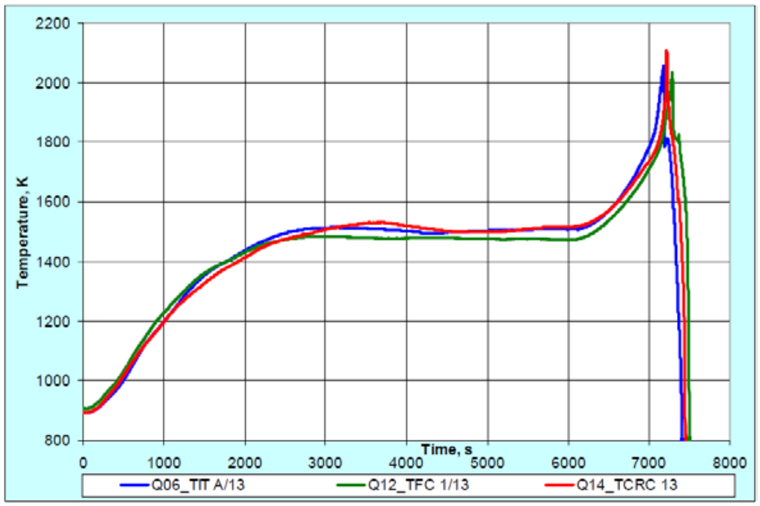

Fig.4 Extreme temperature - experiment

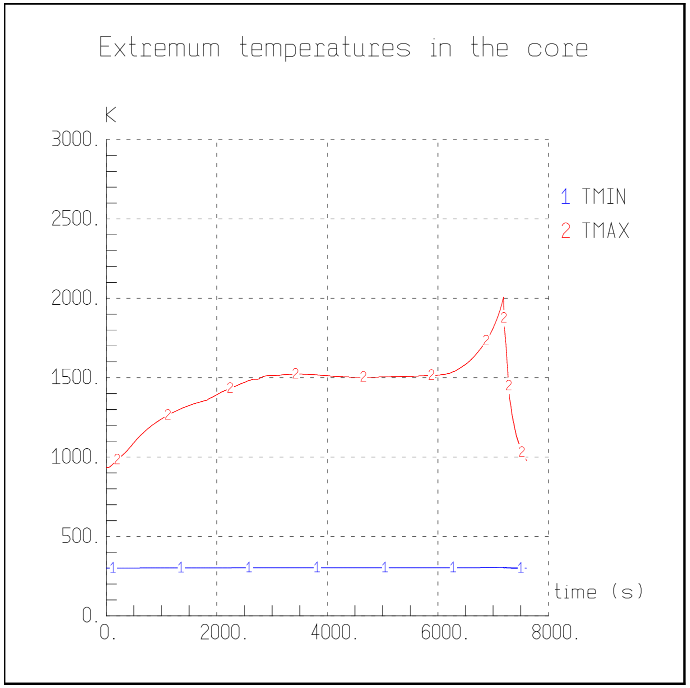

Fig.5 Extreme temperature - ASTEC

Calculated extreme temp. (Fig.4) is close to the experimental data at "hottest" elevation of 950 mm (Fig.5), but the max. calculated value just before quenching is around 2000 K in comparison to 2150 K for the experiment. This difference may be explained with ox. correlation for Zr-4 used for the highest temp-s.

Results by ASTECv2.0R2p2

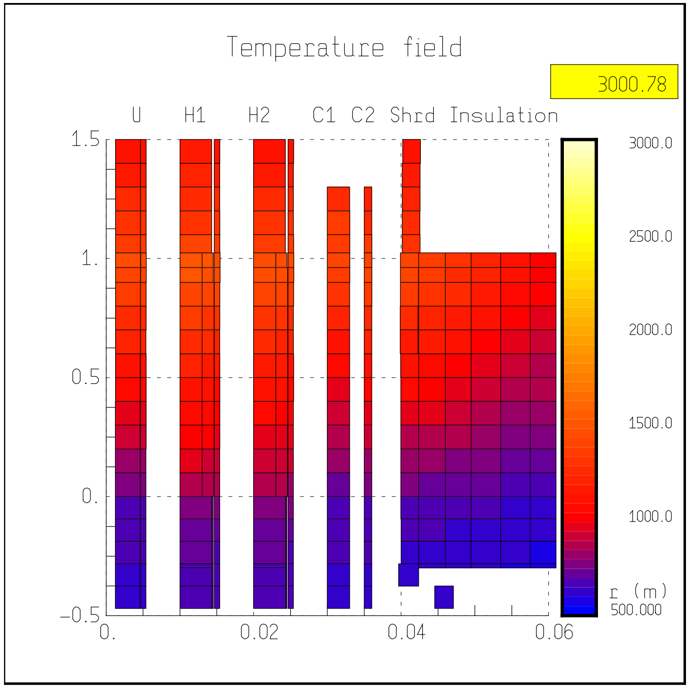

Fig.6 Temperature field, 3000 s - ASTEC

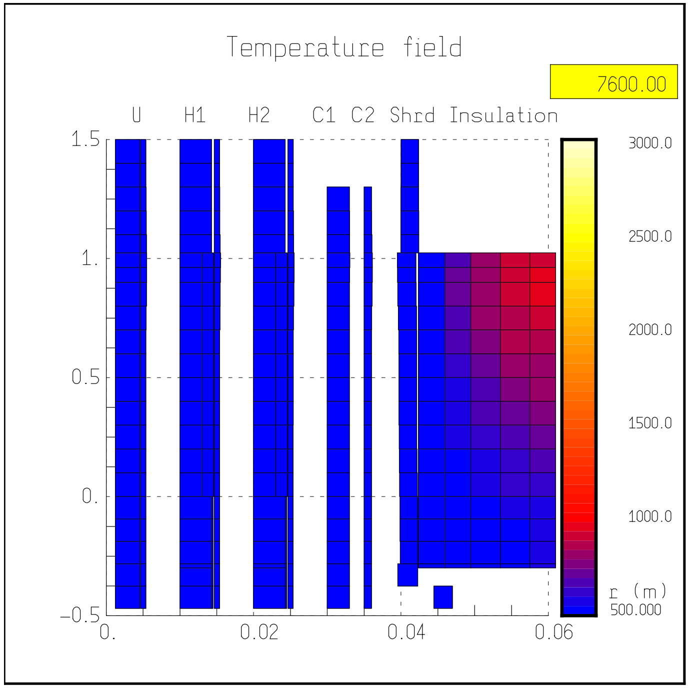

Fig.7 Temperature field, 7600 s - ASTEC

The temp. fields for the central rod (U), heated rod from inner ring (H1), heated rod from the outer ring (H2), two corner rods (C1 and C2), shroud and insulation. The highest temp. before quenching are calculated for height of around 950 mm (Fig.6). In the end of the calculation at 7600 s the highest temp. are calculated over the insulation and the CJ (not presented in the figs) at height around 750 mm (Fig.7).

Results by ASTECv2.0R2p2

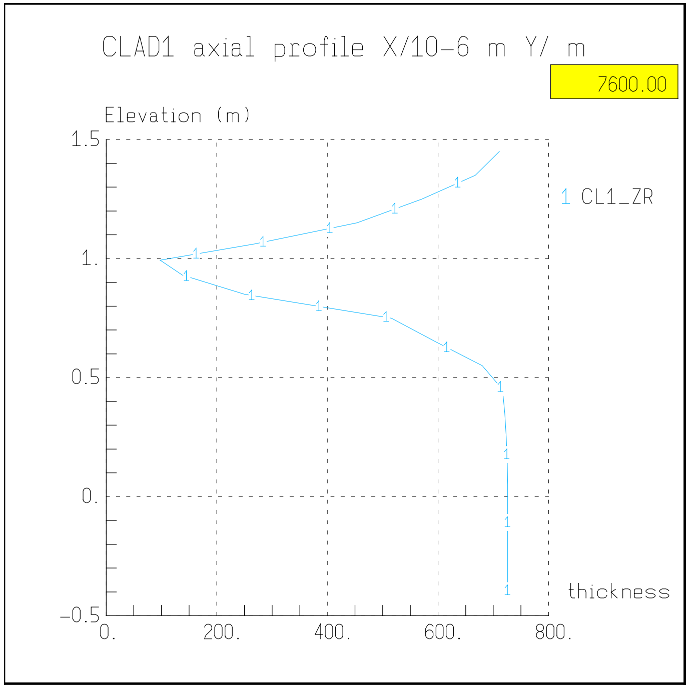

Fig.8 Oxide thickness profile, 7600 s, unheated rod - ASTEC

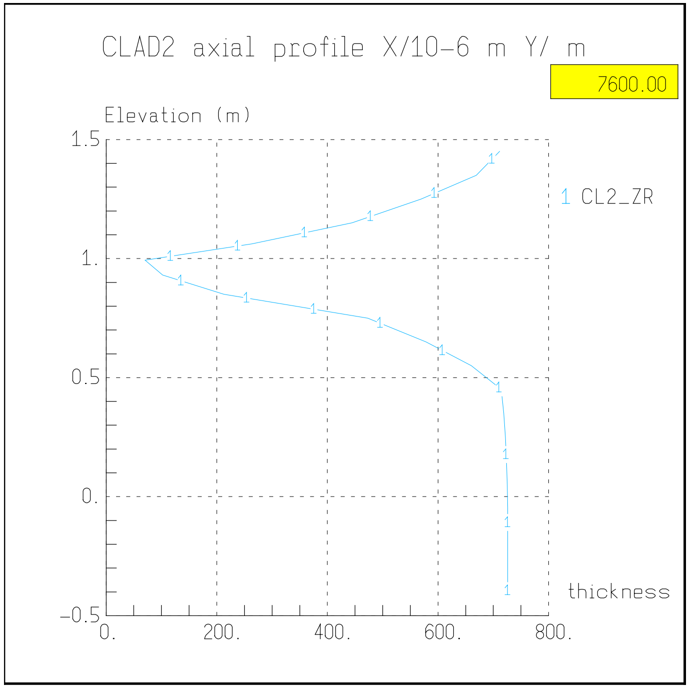

Fig.9 Oxide thickness profile, 7600 s, inner ring rod, 7600 s - ASTEC

The max. oxide thickness calc. by ASTEC for the central unheated rod (Fig.8), is ca 630 µm at a height around 950 mm in comparison to 860 µm at the same height from experiment. At the same height, approx. the same (around 650 µm) is the max. layer thickness for inner ring rod (Fig.9). For the rod from the outer ring, the max. oxide thickness is about 630 µm at the height of ca round 950 mm. In the shroud is calculated oxide thickness is of ca 650 µm: this result is similar to the experimental value of of 590 µm.

Results by ASTECv2.0R2p2

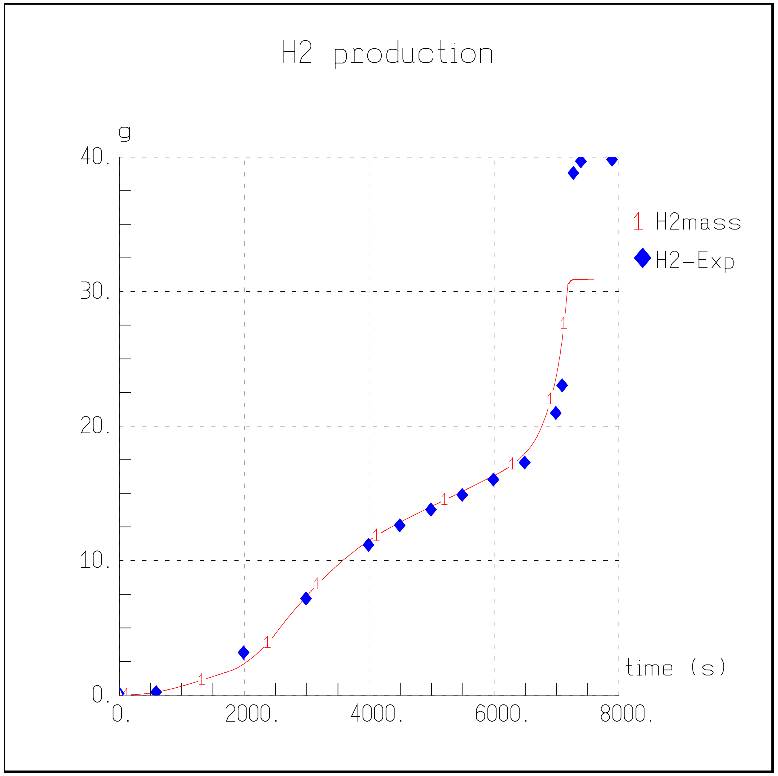

Fig.10 Hydrogen production – experimental & ASTEC

The calculated H_2 production by ASTECv2.0R2p2 is about 32g (40 g in the experiment).

The results obtained by ASTEC are very close to experiment in the phases before quench. Because of the temperatures for the range (1674-2050)K existed data for Zry-4 were used, the obtained results for H_2 production at quench are under-estimated.

The possible reason- need for further modeling of such important phenomena as

1) **hydrogen absorption and release by cladding,**
2) **oxidation of metallic melt formed between cladding and pellets;**
3) **formation of quite thick oxide layer at the inner cladding surface in the region of melt formation.**

Conclusions

- The adapted input decks for QUENCH-14 and the obtained results are similar to experimental data, present possibility for accurate modeling of the processes in the experiment with the newest at the moment version of the code ASTECv2.0R2p2. Although the existence of some little differences in the results, are modeled and visualized some important aspects of the process as the position of the hottest zones and levels in the test bundle, the generation of hydrogen in the different phases, the thickness of the oxide layers, etc.
- The presented simulation for QUENCH-14 is a proof for a lower oxidation rate of M5® for T<1650 K and the lower H_2 generation in the phases before quench.

Thank you for your attention