In Vessel Melt Retention Strategy(IVMR) for VVER 1000 – Status of Work

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ABSTRACT

For GEN III NNPs, first application of the IVMR strategy was developed and approved for the WEC AP 1000 Units and extensive work is carried out for units with high power in China. Our goal is to prepare justification of the IVMR strategy for existing units in operation type VVER 1000/320. At present we have over 100 small scale experiments with very positive results with respect to HF safety margin. However we need to perform not only small scale experiments, but also large scale experiments with fully justified geometry and cooling strategy, supported by qualified analytical assessment. At present large scale experiment is under construction. Analytical support is provided as well. It is very important that our work is part of the HORIZON 2020 IVMR project. Status of overall work will be presented.

1. Introduction

Key conclusions from several recent IAEA TMs are of key importance for strategy of our work:

"It has been highlighted during the IEM and confirmed at the TM that the R&D area regarding in-vessel melt retention and ex-vessel corium cooling/stabilization is one of the highest priority areas, and that more phenomenological knowledge should be gained for the strategic and technological development of the countermeasures to cope with Water Cooled Reactors severe accidents".

With respect to the In Vessel Melt Retention Strategy is necessary realise following IAEA statement:

> "It is commonly recognized that the IVMR strategy achieved by external reactor vessel cooling and/or in-vessel flooding is one of the most effective measures to prevent the progression of severe accidents at water-cooled reactors. Several operating nuclear power reactors (e.g. VVER-440, VVER-1000, Indian PHWR), or new ones (e.g. AP1000, APR1400, CAP1400, KERENA, HPR1000, ACP 1000) use IVMR strategy and have dedicated systems".

As our presentation will provide status of our work on small and large scale experiment is very important to repeat key conclusions on this topic from the recent IAEA TM at SNERDI Shanghai:

Technical Session-1B: External Reactor Vessel Cooling

Two (2) presentations were given on new large experimental facilities, which are designed, based on the lessons learned from small- and large-scale facilities, to measure critical heat flux (CHF) at the outer surface of the RV lower head under more realistic configurations and flow conditions.

One of the two success criteria of the IVMR strategy is ‘thermal criterion’ to make sure the heat flux from in-vessel molten pool is less than the CHF at the outer surface of the RPV lower head that is determined by external cooling conditions with water flooded in the reactor cavity.

Main factors affecting the CHF include: 1) stability of the natural circulation; 2) geometry of the flow path, 3) surface conditions of RV LH, 4) water subcooling at the inlet of the flow path.

Full height experimental facilities are necessary for validation data, and they should be designed as closely as possible to the real conditions.

Based on the results from small-scale experiments, the most effective measures to increase CHF might be optimisation of the flow path and the outer RPV surface conditions of the lower head.

2. Small scale experiments – Status of Work

2.1. Design

It is important to realize size of the small scale experiment, cooling channel configuration and also position of thermocouple used for identification of the boiling crisis. Those data are seen from following two figures.

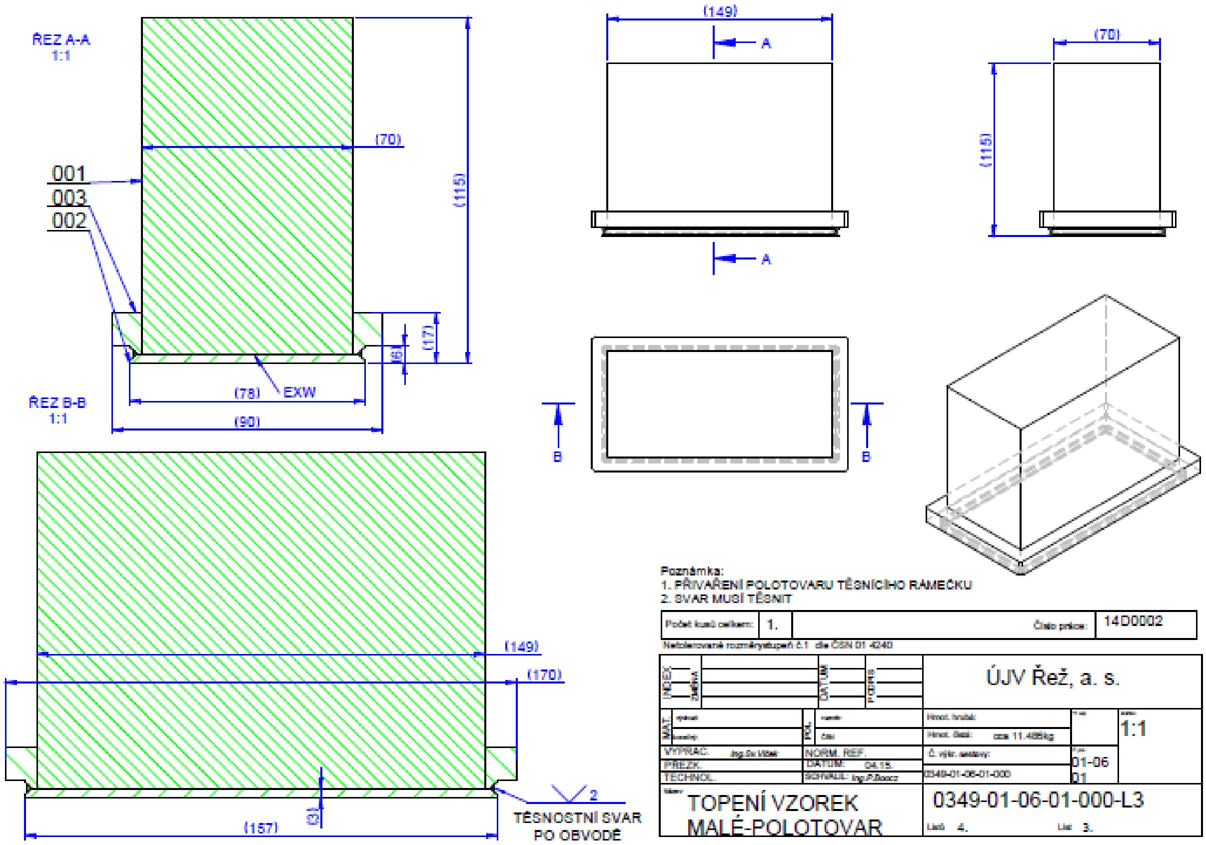


Fig.1. Dimension of small scale sample. Steel surface explosively welded with Cu bloc.

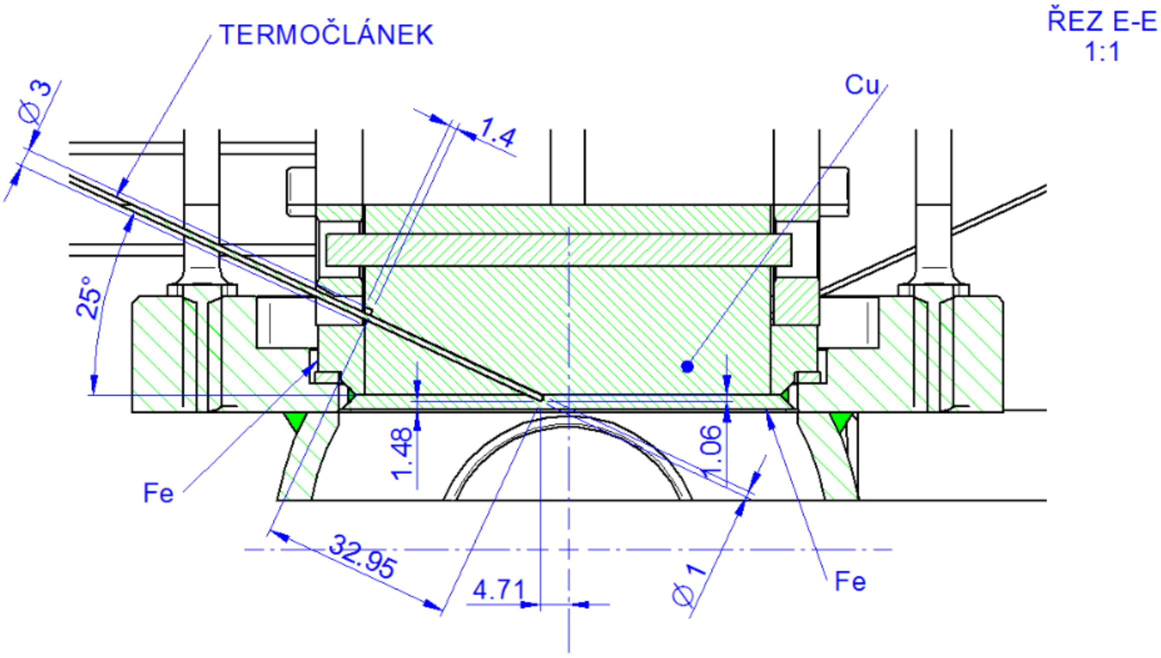
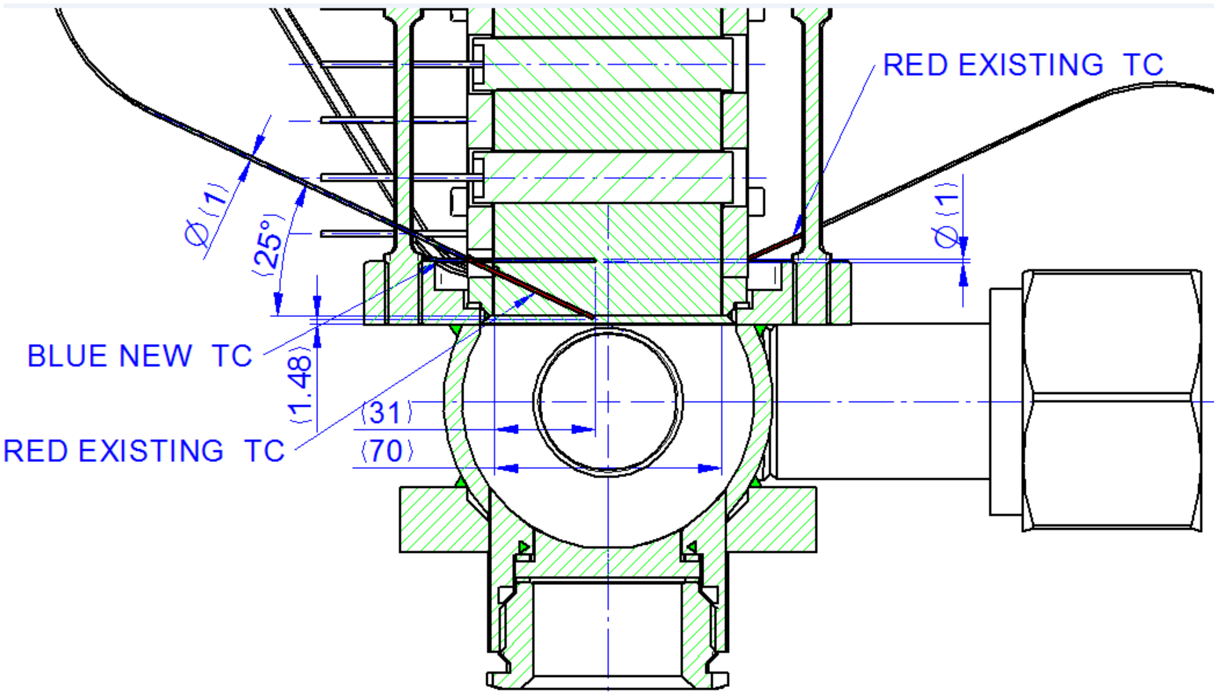


Fig. 2. Detail position of the thermocouple used for boiling crisis identification.

Very recently we have decided to install more thermocouples near the steel surface in order to measure more temperature profile data to get better estimation of the Heat Flux. Tests are in progress and if results will be helpful we will consider similar measurement in the large scale test blocs.



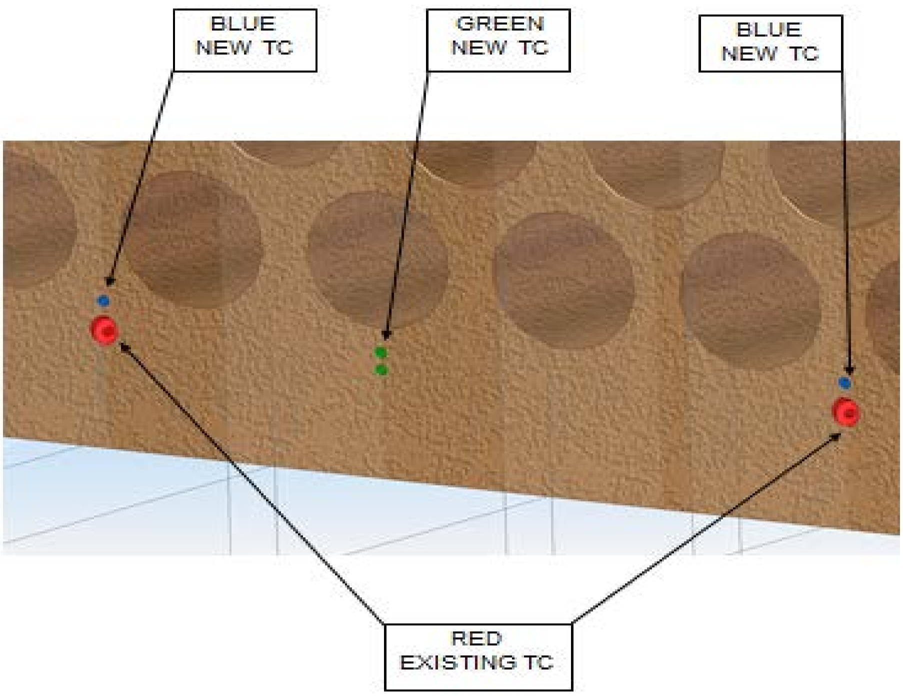


Fig.3. New thermocouple positions in the small scale sample.

Fig.4. Test sample with heating patrons and thermocouple position

2.2. Summary of results and lessons learned

Over 130 experiments were performed on the small scale facility. Without technical lessons learned from the design and performance of the small scale tests it will be extremely difficult to build the large scale facility. Most important knowledge is fully verified explosive welding technology between the steel plate and Cu bloc segments. Latest, additional temperature measurement is also very important. Our research effort is also focused on effect of the steel surface. Great design advantage of the VVER 1000 units is an access to the RPV cavity with possibility to identify status of the RPV surface after several years of operation and possibility to apply justified surface treatment on the critical RPV surface where we need to assure most effective heat flux removal. Based on that knowledge and feasibility to do that in real configuration of operated rector we have decided to apply most effective surface improvement. With great support from the ARL/PSU we are until today testing the "cold spray „ technology with different composition of particles. On top of it we are testing our own surface treatment technology. Summary of all results obtained until now are presented on Fig.5. Tests on small scale facility will continue in order to decide representative test matrix on the large scale experimental facility.

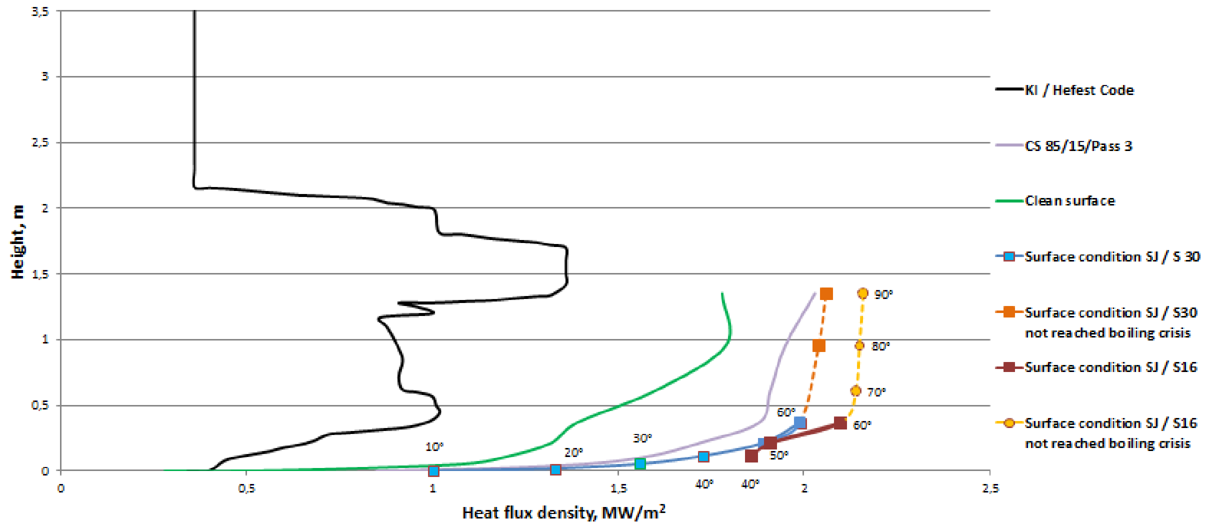


Fig.5. Summary of experimental results with different surface treatment.

2.3. Summary of small scale test results

Design knowledge and experience is of great value for large scale facility. Results of tests, with significant number performed, clearly shows improvement to be reached with respect to the heat flux removal. It is important to stress that tested technology has to be applied on existing VVER 1000 design under operation. Technology applied must not affect performance of the NDE tests from the outside RPV surface and also cannot influence the RPV integrity and overall safety requirements.

4. Large Scale Experimental Facility THS-15

4.1. Principal Design

Fig.6 is providing basic design of the cooling channel. Most important are dimensions between the RPV cavity floor and wall between steel surface simulating shapes of the RPV lower head and cylindrical wall. Also input of the cooling water through the cavity floor and steam release dimension corresponding to the available space between the support ring and the RPV wall. Inside the cooling channel is also possible to install deflector steel plate.

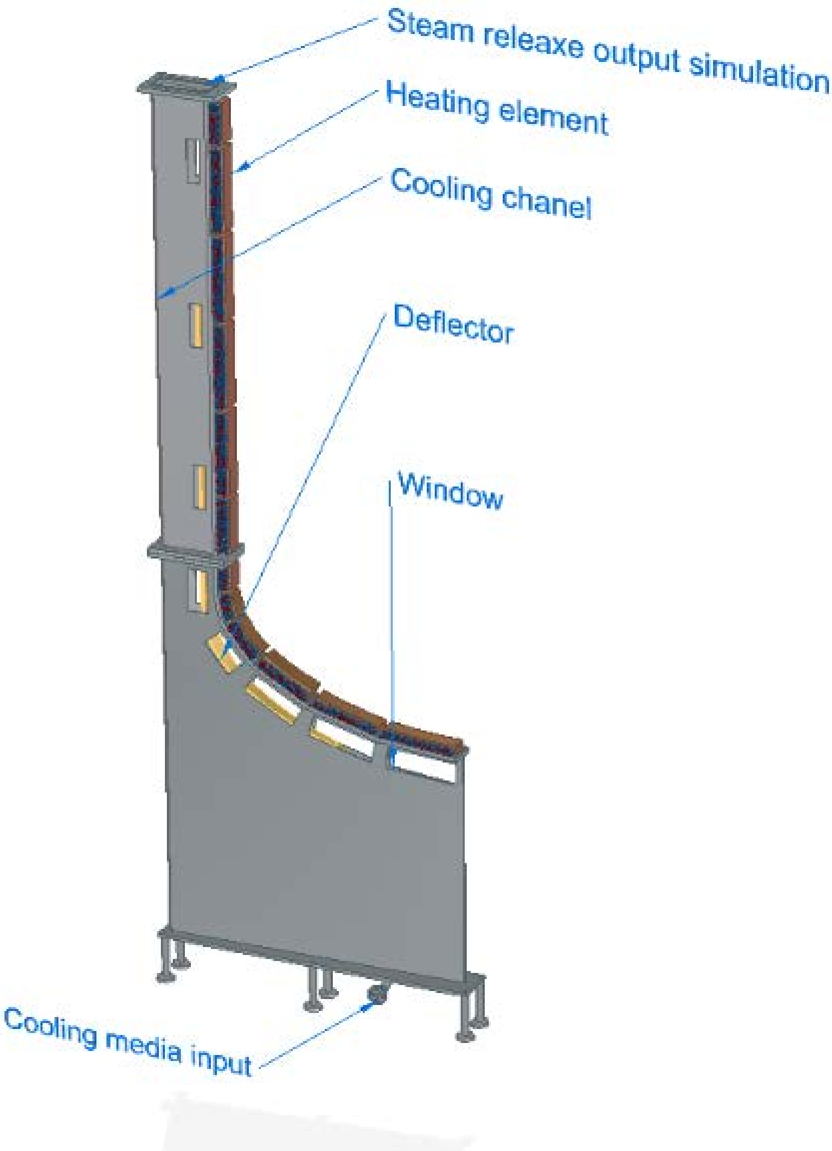


Fig. 6 Cooling channel basic design

Overall design of the large scale test facility THS-15 is seen on Fig.7. To meet all design requirements in existing building it was necessary to plan significant civil reconstruction including drilling holes to existing floor, new installation of electrical cables, and many other activities.

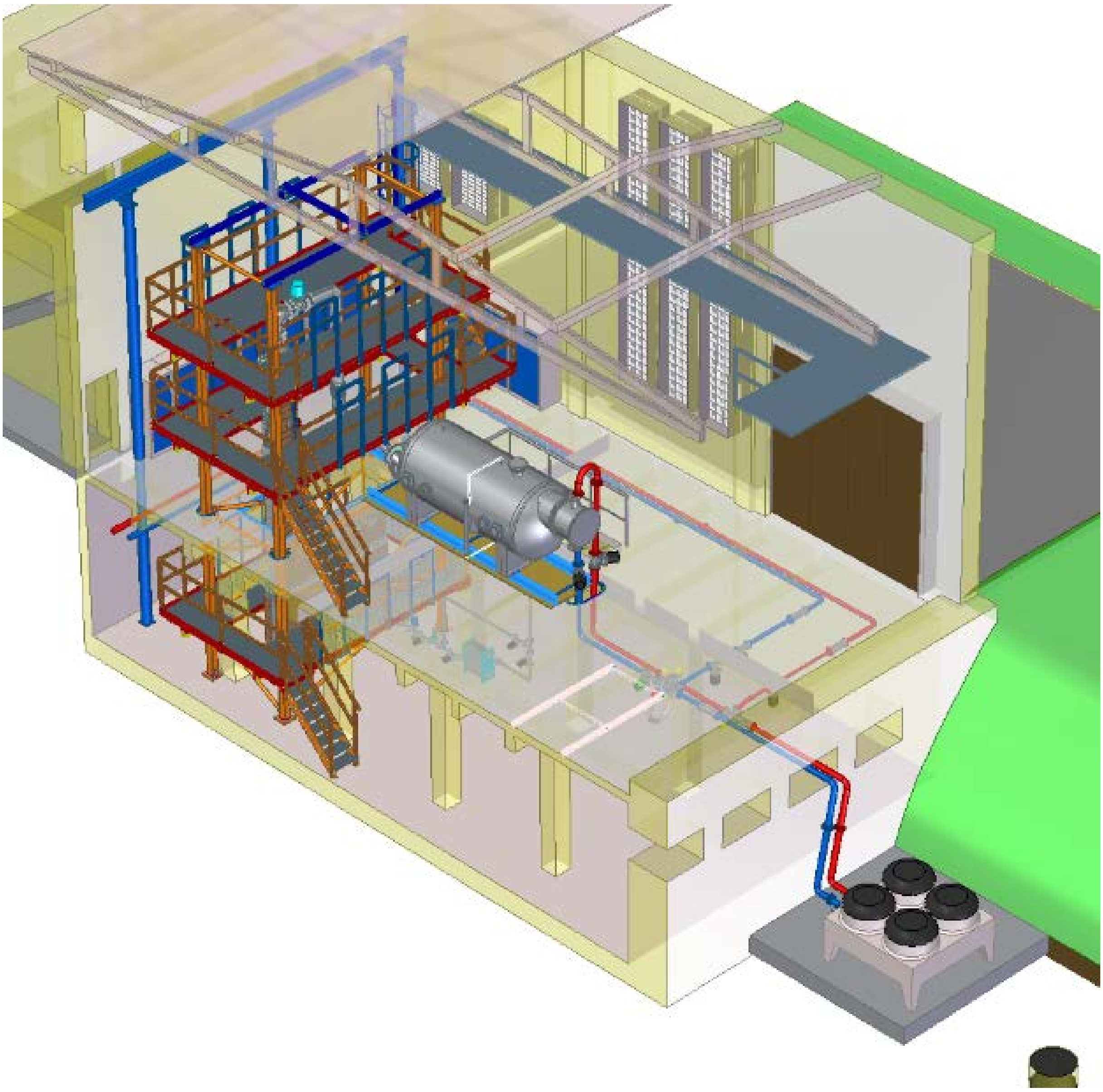


Fig.7 Large scale test facility THS-15 principal design drawing.

4.2. Status of Civil Construction

Installation of new electrical cables started civil construction work. Detail is seen on Fig. 8

Fig.8 New electrical cables installation.

In December 2016 all civil construction work was finished. On Fig. 9 is seen drilled rectangular opening in the floor for installation of cooling channel with support construction.

Fig. 9 Photo of rectangular floor opening for the cooling channel installation.

4.3. Status of Manufacturing of Key Components

In February 2017 will be finished segments of all heater blocs with drilling of more than 1300 heating patrons. Drilled holes in one of the heater segment are seen on Fig. 10.

Fig.10 Heater segment with drilled holes.

In January 2017 we plan to install condenser and other key components. Design of the cooling channel was delayed due to new integrity calculations and also due to thorough welding qualification process and tests. Manufacturing will start in February 2017.

4.4. Remaining schedule for large scale test facility build up.

Original schedule to finish large scale test facility THS-15 in order to start final set up for the test matrix is planned on April 2017. We are significantly ahead of schedule with respect to the HORIZON 2020 IVMR TASK 4 schedule. However our Czech Utility would like to make decision about the IVMR application for our VVER 1000 Units at Temelin site in November 2017 and till that time there is a need to have at least basic large scale tests results. As you could see our schedule to meet this deadline is very hard. Our team is performing with highest responsibility to meet the above deadline with minimum delay.

5. Conclusion

Overall project is possible to perform thanks to the great team work. Small scale experiments are running in parallel with civil construction work for the large scale facility. As already mention results from small scale tests are providing already significant margin with respect calculated heat flux profile calculated by Kurchatov Institute in Moscow. Such a result we have reached thanks to special steel surface modifications. Small scale results are not yet finished and we expect further increase of margin to the calculated heat flux. Building the large scale experiment is real challenge. It is necessary to mention that at present only two countries are extensively studying the coolability of the RPV outer surface. Even every day technical problem we are progressing forward and focusing to build reliable cooling channel where we could perform complex test matrix. During the Conference we will be ready to provide you update of our team work and results.