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# VERIFICATION OF THE KNI-LM ASSEMBLY FOR THE REACTOR COOLANT LEVEL MONITORING SYSTEM

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*The monitoring system RVLIS (Reactor Vessel Level Instrumentation System) which was installed during the recent modernization of NPP Dukovany and NPP Bohunice acquires the signals from two special developed KNI-LM assemblies located inside the reactor. The quality of heat transfer from this assembly to surroundings determines the value of detected temperature difference which is essential for coolant level indication in reactor and this quality is studied in this paper. The results of the KNI-LM assembly test measurement and numerical simulations indicate the correct function of this assembly.*

**Key words:** pressure water reactor, reactor pressure vessel coolant level, KNI-LM assembly, heating element, thermocouple

## 1. Introduction

Present safety regulations for operation of the nuclear power plant (NPP) with pressure water reactor require having another independent system for detection of the sufficient volume of primary coolant. This diversified system has to be independent on the level measurement inside the pressurizer and it has to indicate the coolant level inside the reactor pressure vessel (RPV). This requirement is based upon the bad experience with the coolant level measurement during the accident at the unit 2 of the NPP Three Mile Island, USA, in March 1979. At that time it turned out that monitoring of the coolant volume with the help of coolant level measurement inside the pressurizer is not reliable and satisfactory.

Both at two units of the NPP Jaslovske Bohunice – V2 (EBO-V2, commissioned in 1984 – 1985) and at four units of the NPP Dukovany (EDU, commissioned in 1985 – 1988) the volume of the coolant was primarily monitored only by level measurement inside the pressurizer. In the scope of the modernization of both NPPs it was possible to install and put into operation the special monitoring system RVLIS (Reactor Vessel Level Instrumentation System) at each reactor unit. This system was developed especially for the coolant volume monitoring at pressure water reactor of type VVER 440, see [1], [2] and [3]. The RVLIS system evaluates the thermocouple signals (and their differences) which are measured with the help of specially designed and fabricated KNI-LM assemblies placed into the RPV, see [4].

The system RVLIS for monitoring of the coolant level inside the reactor pressure vessel type VVER 440 is designed and qualified as a part of system PAMS (Post Accident Monitoring System). All of the RVLIS components meet the requirements for seismic and LOCA (Leak of Coolant Accident) qualification related to their determination and location.

## 2. The measurement principle and design of the KNI-LM assembly

The KNI-LM assembly for coolant volume monitoring and for indication of coolant level occurrence inside the RPV was created on the base of the commonly used KNI assemblies (from Russian Kanaly nějtronnovo izměrenija). These assemblies have in its lower part the self powered (beta-emission rhodium) detectors (so called DPZ or SPD – see **Fig. 1**) for the neutron flux detection inside the reactor core. In the upper part of the KNI-LM assembly, there are additionally placed three measuring points in vertical direction, i. e. three electrical heat elements, three thermocouples for measuring their temperature – so called heated thermocouple (HTC) and two reference thermocouples (REF) for the ambient temperature monitoring. Both electrical heat elements and thermocouples are pragmatically distributed along the axial axis of the KNI-LM assembly.

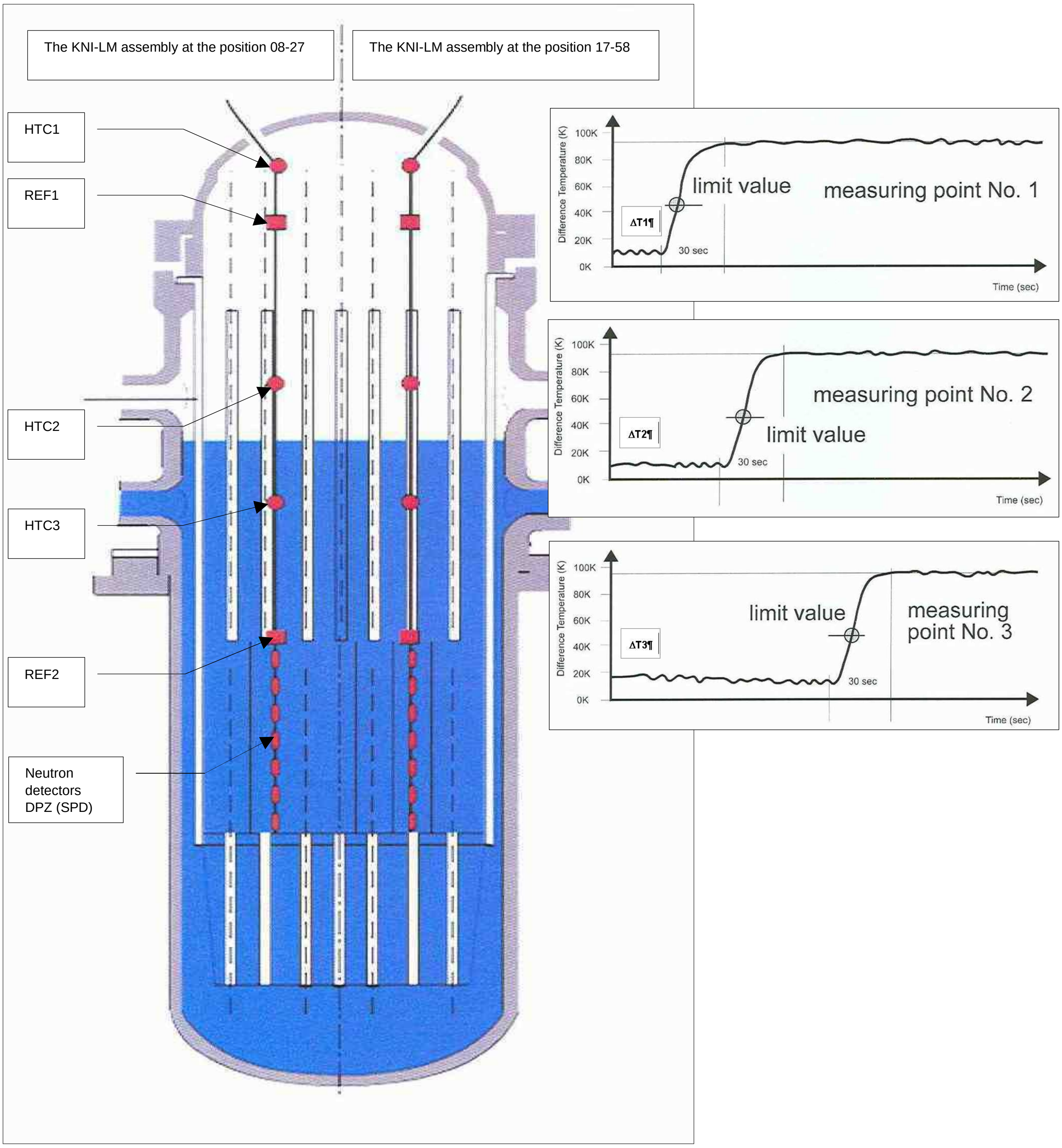


**Fig. 1:** Scheme of the KNI-LM assembly positions inside the reactor of VVER 440, axial locations of the thermocouple and characteristic time history of the temperature difference during phase change of surroundings

The measuring principle is based on the fact that special electrical heating element has lower temperature when it is immersed in water than when it is surrounded by saturated steam. It means the thermocouple measuring temperature of the heating element measures the lower temperature when the measuring point is immersed in water then in steam. The unheated thermocouples are used as reference measurement points for the reason the measurement to be independent on the ambient temperature (water or saturated steam). The value of the difference between HTC and REF signals is used for indication of the coolant level inside the reactor.

The coolant level alarm is evaluated when the difference between the HTC and REF signals exceeds specific limit and the signal of coolant level under the measuring point (HTC) is indicated. The axial resolution of each measurement point is ±50 mm and the time of response after the limit reach is less than 30 s. The typical time history of temperature difference affected by variation of ambient condition phase is depicted in **Fig. 1**.

There are two KNI-LM assemblies in each RPV at the above mentioned NPPs. All thermocouples are manufactured with good heat contact with the inner surface of assembly tube. The heating elements installed inside the assembly have good heat contact with HTC. There are installed K-type thermocouples (NiCr-Ni) with the sensitivity approx. 40 μV / °C in the KNI-LM assembly. A special wire also made of special alloy NiCr-Ni is used as the heating elements.

Individual measuring points have the following marking and position (down from top, see **Fig. 2**):

HTC1 – under the RPV head
REF1 – under the RPV head
HTC2 – level of the RPV outlet nozzles
HTC3 – level of the RPV inlet nozzles
REF2 – level of coolant outlet from the core

Thermal differences between individual thermocouples are defined as follows:

ΔT1 [K] = HTC1 – REF1
ΔT2 [K] = HTC2 – REF2
ΔT3 [K] = HTC3 – REF2

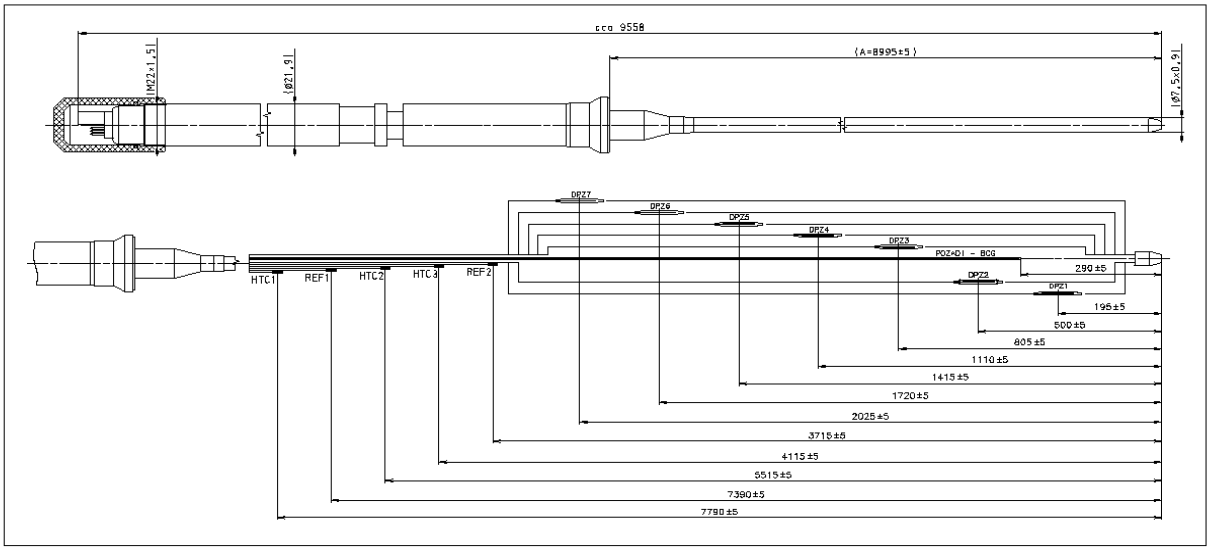


**Fig. 2:** Detail scheme of the KNI-LM assembly and location of the individual measuring points

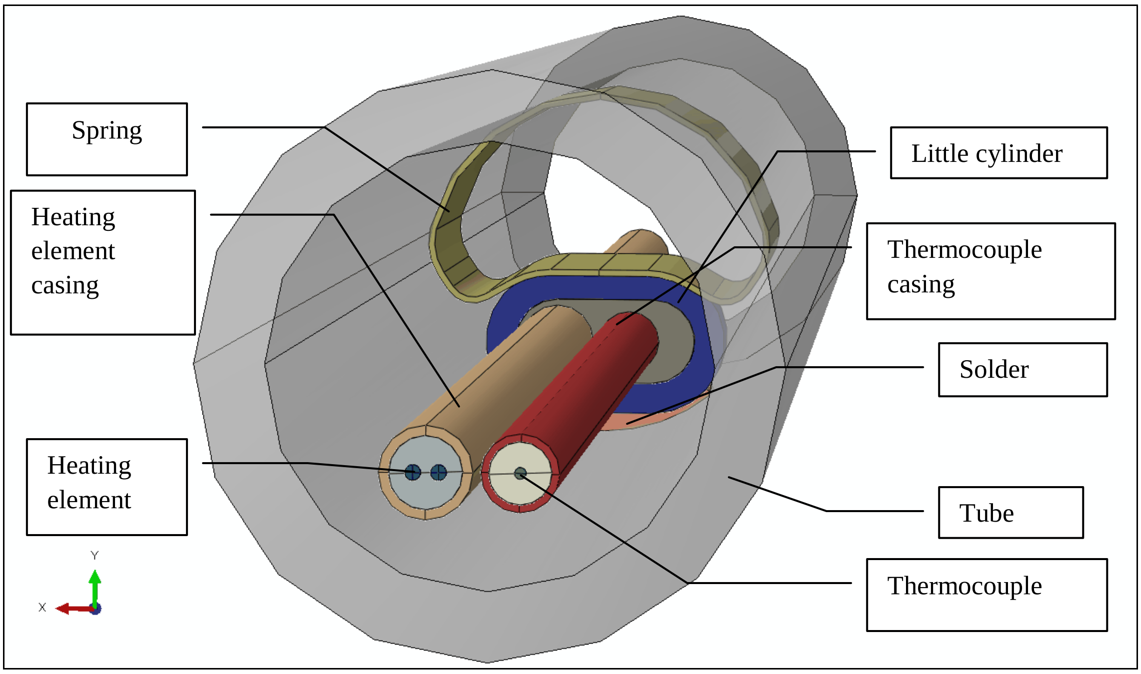


**Fig. 3*:*** Geometrical and material model of one measuring point (HTC 1) inside the KNI-LM assembly

One of the most important factors for correct function of the KNI-LM assembly (and hence the correct function of the whole RVLIS system as well) is the correct heat transfer from heating element located inside the assembly into the ambient surrounding outside surface of the KNI-LM assembly. The heat transfer quality determines the value of detected temperature difference, which is essential for coolant level indication in RPV. That is why just the quality of measuring point manufacturing and the effects of the solder and of the spring (see **Fig. 3**) are studied in the following chapters.

## 3. Functional tests with the experimental KNI-LM assembly

The aim of the functional tests with the specially made experimental KNI-LM assembly was to assess an effect of the manufacturing quality for each measuring point on the correct KNI-LM assembly function in the sense of sufficient quick and credible detection of the coolant loss in the RPV in the given measuring point. This quality is represented by the quality of soldering of the heating element and the corresponding thermocouple to the inner surface of the KNI-LM assembly tube.

Simultaneously, the object of the functional tests was to obtain realistic and reliable details for the verification/validation of the created mathematical simulating models of particular measuring points. These certificated mathematical models can be used for further simulations of realistic situations inside the reactor including fault conditions of the KNI-LM assembly.

The specially made experimental KNI-LM assembly has the same design as the KNI-LM assemblies installed at the NPP Dukovany and the NPP Bohunice – V2 but it is shorten only to the (upper) coolant level part. It is equipped with three heating elements (connected into series), with three HTC and with two REF (**Fig. 4**). The resistance thermometer (RTD) of type Pt100 is installed inside the KNI-LM assembly connector.

There are used thermocouples of K-type with the outer casing diameter 1 mm in the KNI-LM assembly. Both all of the thermocouples and the heating elements are soldered into so called little cylinders in the right way. But the individual contacts between little cylinder and inner surface of the specially made experimental KNI-LM assembly are manufactured with different modifications which simulate different quality of this contact, see **Fig. 4**.

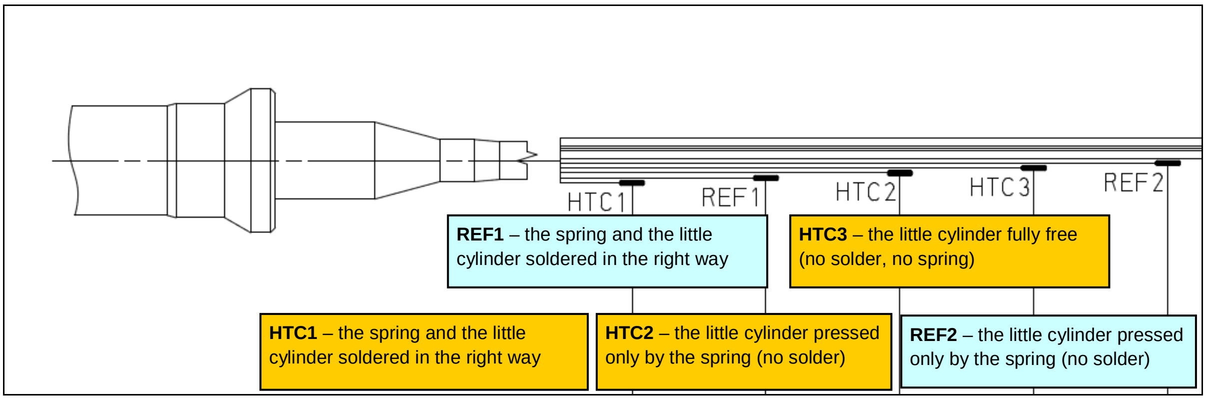


**Fig. 4:** Scheme of the specially made experimental KNI-LM assembly and different modifications of the measuring points

The test results for the specially made experimental KNI-LM assembly are put on in the form of the temperature time history in the figure **Fig. 5**.

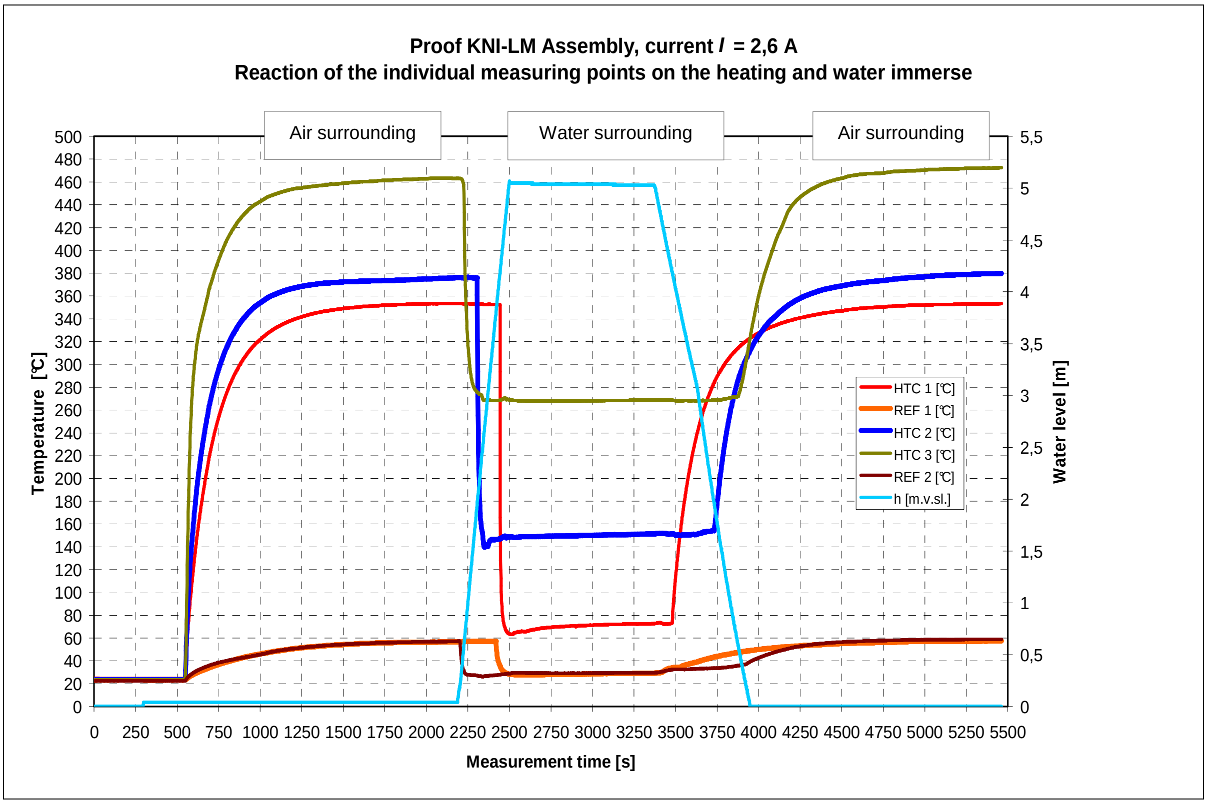


**Fig. 5**: The test results for the proof KNI-LM assembly

The presented graphs show that absence of the solder has magnificent effect on the heat transfer in the KNI-LM assembly. But absence of the solder and parallel absence of the spring press force have even bigger effect. At this moment it is possible to claim that the KNI-LM assembly holds its ability of coolant level beginning detection even in the worst state of the measuring points.

## 4. Mathematical model

The Finite Element Method (FEM) was used for creation of the KNI-LM assembly 3D simulation model and subsequent heating analysis and real condition simulations. Based on the ŠKODA JS technical documentation, the spatial geometrical model of the KNI-LM assembly with all details was created (**Fig. 3**). Due to the computation time minimization, only the small part of length (200 mm) was considered in the model instead of the real length of 9,5 m (**Fig. 2**). The simulation models were created in three configurations HTC 1, HTC 2, HTC 3 (**Fig. 6**) that corresponds to individual measuring points in the experimental KNI-LM assembly (**Fig. 4**). In accordance with the experiment the KNI-LM assembly was situated both in water and in air (**Fig. 5**). "Coupled thermal – electric (Steady-State)" type of step was performed in this model, therefore the heat transfer material properties (coefficients α [W/m$^2$/K], λ [W/m/K]) had to be defined beforehand. These values and their temperature dependences for each used material were obtained from the literature sources [5]. Computational FEM mesh of the most of component parts was built by the 8-node linear heat transfer brick (DC3D8) or 10-node quadratic heat transfer tetrahedron (DC3D10) elements. The constraint between component parts was realized by so-called surface-based "TIE".

The heat generated in the heating element was defined by the "body heat flux " function. The value of "body heat flux" depends on the applied electrical current (2,6 A) and on the length of the heating element. Boundary conditions were defined by the coefficient of heat transfer to ambient surrounding outside the KNI-LM assembly (water, air). The contact with ambient surroundings was defined as a "surface film condition". The natural flow heat transfer dominates in the condition of water; on the other hand the heating radiation dominates in air.

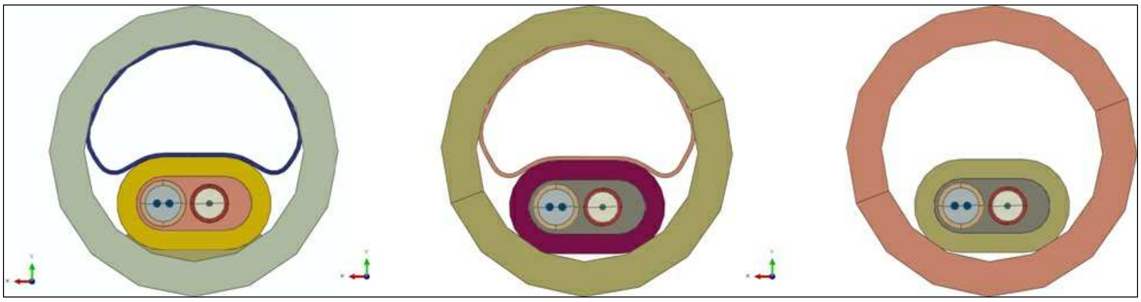

**Fig. 6:** Simulation models corresponding with the different manufactured measuring points
HTC 1 (with the spring and solder) HTC 2 (without solder) HTC 3 (without solder and spring)

## 5. Results

The calculated temperature was determined from the thermocouple tip model (the end part fixed in the little cylinder (**Fig. 7**)). Three configurations of KNI-LM assembly (HTC 1, HTC 2 and HTC 3) in water and in air were evaluated.

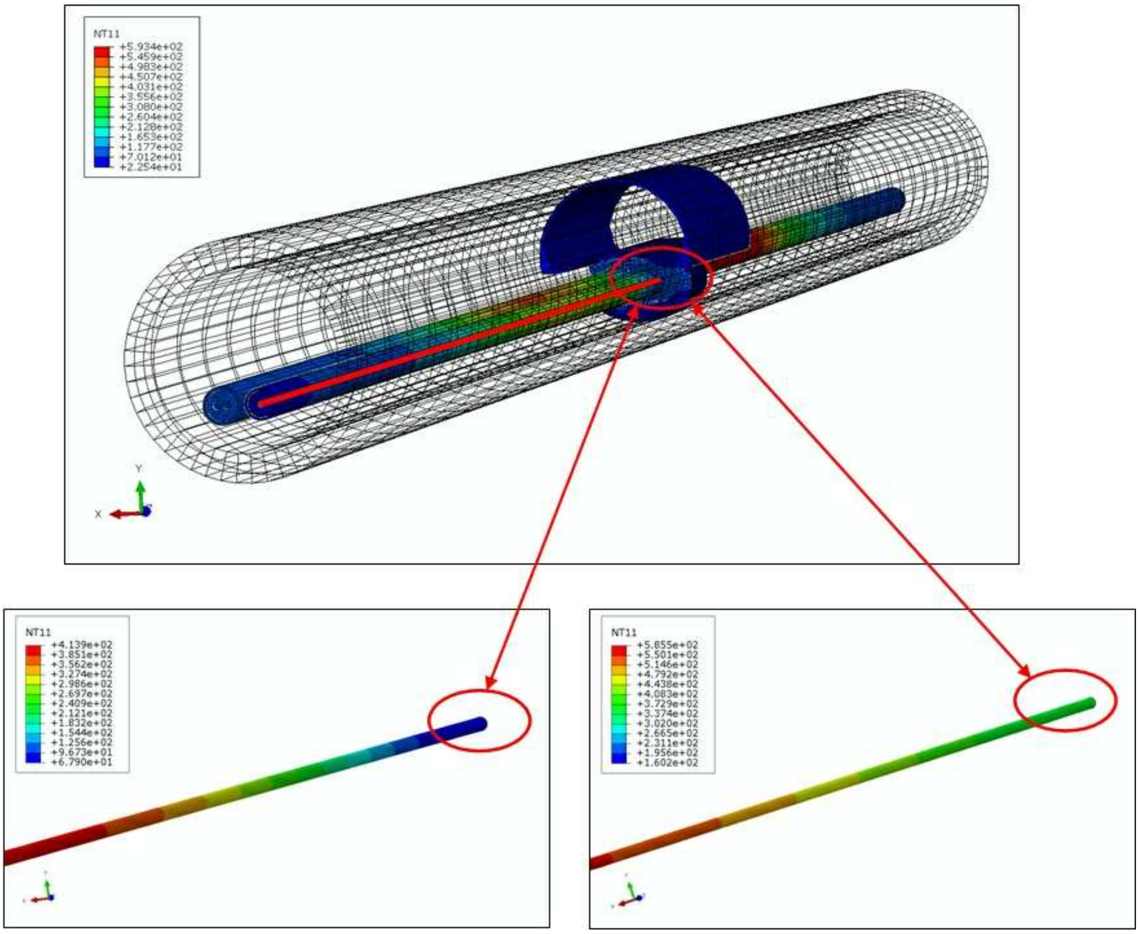


**Fig. 7:** Maximum calculated temperature in water [°C] and the detail view on the thermocouple tip (70 °C in water and 350 °C in air)

The comparison of the experimental and mathematical model results was the aim of this study (**Tab. 1**).

| KNI-LM ASSEMBLY MEASURING POINT CONFIGURATION | TEMPERATURE IN WATER [°C] MAT. MODEL / EXPERIMENT | | TEMPERATURE IN AIR [°C] MAT. MODEL / EXPERIMENT | |
|---|---|---|---|---|
| HTC 1 | 70 | 70 | 350 | 350 |
| HTC 2 | 91 | 150 | 366 | 370 |
| HTC 3 | 300 | 270 | 500 | 460 |

**Tab. 1:** Temperature [°C] results of the KNI-LM assembly calculation and test configurations

The results of the mathematical model were in good accordance with the experimental data in the configuration HTC 1 (water, air) and HTC 2 (air). The configuration HTC 2 (water) differs by about 60 %, this difference was probably caused by the contact spring/cylinder conditions.

The contact was constructed fully (whole surface of spring to be in contact) in the mathematical model and there was continuous heat dissipation in this case. On the contrary, in the real situation (experiment) the spring is connected with little cylinder by so called spot welding method (not whole surface to be in contact). The configuration HTC 3 (water, air) differs by about 10 %.

## 6. Conclusion

The objective of this study was the comparison of the experimental measurement results (**Fig. 5**) and the results obtained from the mathematical FEM simulation of the KNI-LM assembly (**Tab. 1**). The results of temperatures measured on the thermocouple in the conditions water/air nearly correspond with each other in all observed configurations (**Tab. 1**). The KNI-LM assembly functionality was verified. The verified calculation model will be further used to verify functionality of the KNI-LM assembly in the operational conditions of reactor and to optimize heat current for the specific type of reactor. The acquired results of experimental as well as calculation part will be used for other types of tasks in the field of operational state simulations and they are significantly important in the field of safety measurement of nuclear energy.

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