A.P. Alexandrov Research
Institute of Technology (Russia)

ISTC
МНТЦ

# Progress Report on the ISTC project #3592 "Investigation of Corium Melt Interaction with NPP Reactor Vessel Steel" (METCOR-P)

Prepared by V. Granovsky and A. Sulatsky
Presented by S. Bechta
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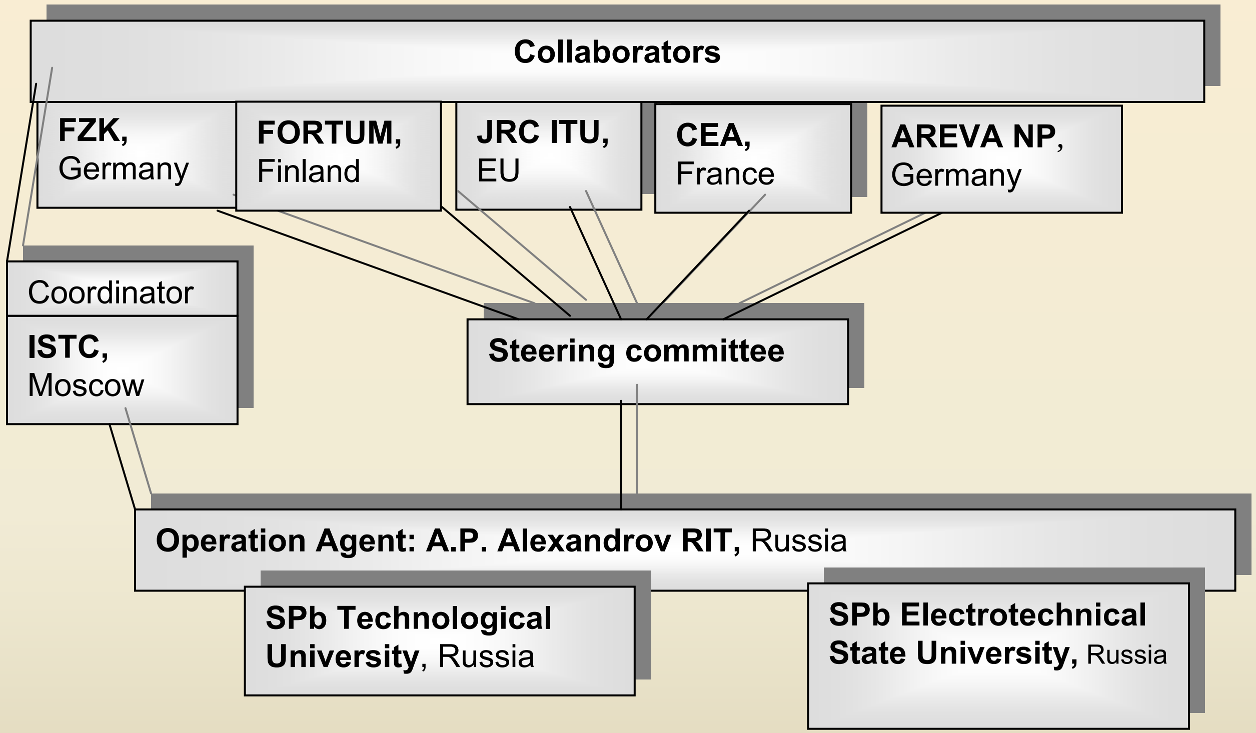
# METCOR-P project general information

## Investigation of Corium Melt Interaction with NPP Reactor Vessel Steel (#3592 METCOR-P)

### Project participants and coordination




| | |
|---|---|
| Project duration | 36 months |
| Financial party | Europe |
| Project status | Started in April 2007 |

# Objectives of METCOR-P project

**Qualification and quantification of physicochemical phenomena of corium melt interaction with reactor vessel steel with particular interest to:**

- Interaction characteristics at the vertically positioned interface
- Peculiarities of interaction with European vessel steel
- Corium melt oxidation transients

# Experimental matrix for METCOR-P project

| # | Item | Experimental conditions | | | Notes |
|---|---|---|---|---|---|
| | | Composition | Surface temperature, °C | Atmo-sphere | |
| 1 | Interaction at vertically positioned interface | $UO_2$ -$ZrO_2$ C100 | 1400 (Steel) | Ar | Reference-test * |
| | | $UO_2$ -$ZrO_2$ -Zr C30 | | | MCP1: MC6 conditions |
| | | Fe-U-Zr-Cr-Ni-O | | | Metallic phase of the melt enriched with U and Zr |
| 2 | Interaction at molten corium oxidation transients | $UO_2$ - $ZrO_2$ -Zr C30 with vessel steel specimen | | Ar steam | 10-hour exposure in Ar until the interaction stabilizes. Replacement of Ar with steam after it |
| | | $UO_2$ -$ZrO_2$-Zr C30 without vessel steel specimen*** | 2500 (Melt) | | The oxidic melt is in contact with a calorimeter |
| | | Fe-U-Zr-Cr-Ni-O without vessel steel specimen*** | | | Molten metal enriched with U and Zr is in contact with a calorimeter |
| 3 | Interaction of molten corium with european vessel steel | $UO_2$ -$ZrO_2$ -Zr C30 | 1400 (Steel) | Ar | 20 MnMoNi5-5 steel – was provided by collaborators |
| | | $UO_{2+x}$ -$ZrO_2$ $UO_{2+x}$ -$ZrO_2$ -$FeO_y$** | 1300 (Steel) | Air** | |

***) In accordance with the 1st project meeting decision it is replaced by MCP-2 test with $UO_{2+x}$– $ZrO_2$ corium in air and horizontal position of interface**

****) In accordance with a decision taken at the 3rd project meeting, the test was performed in air (instead of steam) and regimes with $UO_{2+x}$ - $ZrO_2$ - $FeO_y$ melt were added**

*****) MCP-6, 7 test procedure was discussed at the 4th project meeting**

# Interaction of suboxidized molten corium with European vessel steel

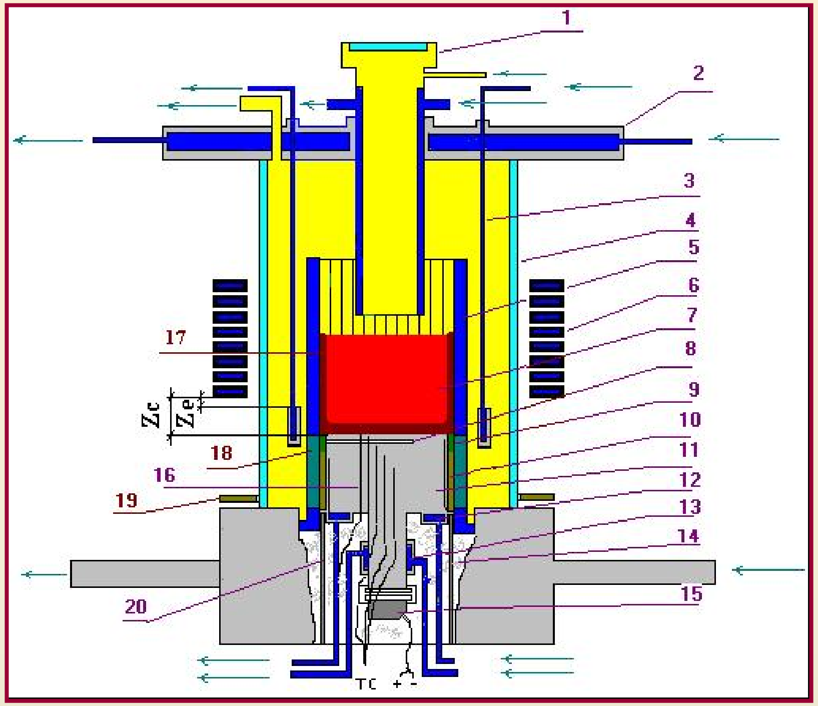
## TEST MCP-5

## Objectives

- Comparison of the corrosion rate and depth for European and Russian vessel steel at its interaction with suboxidized molten corium

# RASPLAV-3 Installation

## Furnace schematics




**1 –pyrometer shaft; 2 –cover; 3 –electromagnetic screen; 4 – quartz tube; 5 – crucible section; 6 – inductor; 7 –melt; 8 – acoustic defect; 9 – molten $ZrO_2$; 10 –$ZrO_2$ powder thermal insulation;**

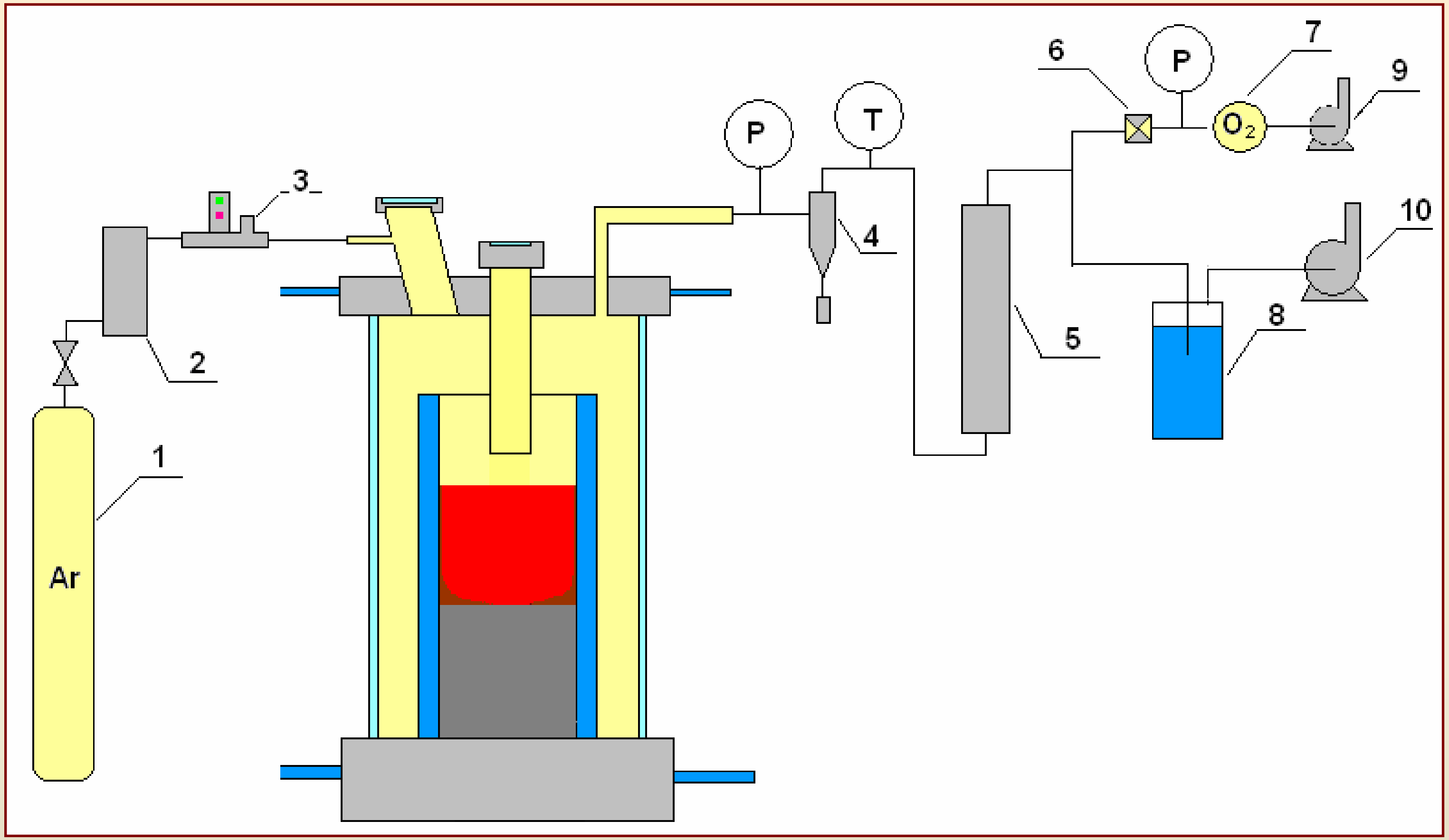
**11 – vessel steel specimen; 12 –top calorimeter of the specimen;**

**13 – bottom calorimeter of the specimen; 14 – kaolin wool insulation; 15 –ultrasonic sensor;**

**16 –thermocouples; 17 – crust, 18 – electromagnetic screen; 19 – uncooled electromagnetic screen;**

**20 – cylindrical support of the specimen**

# Gas-aerosol system

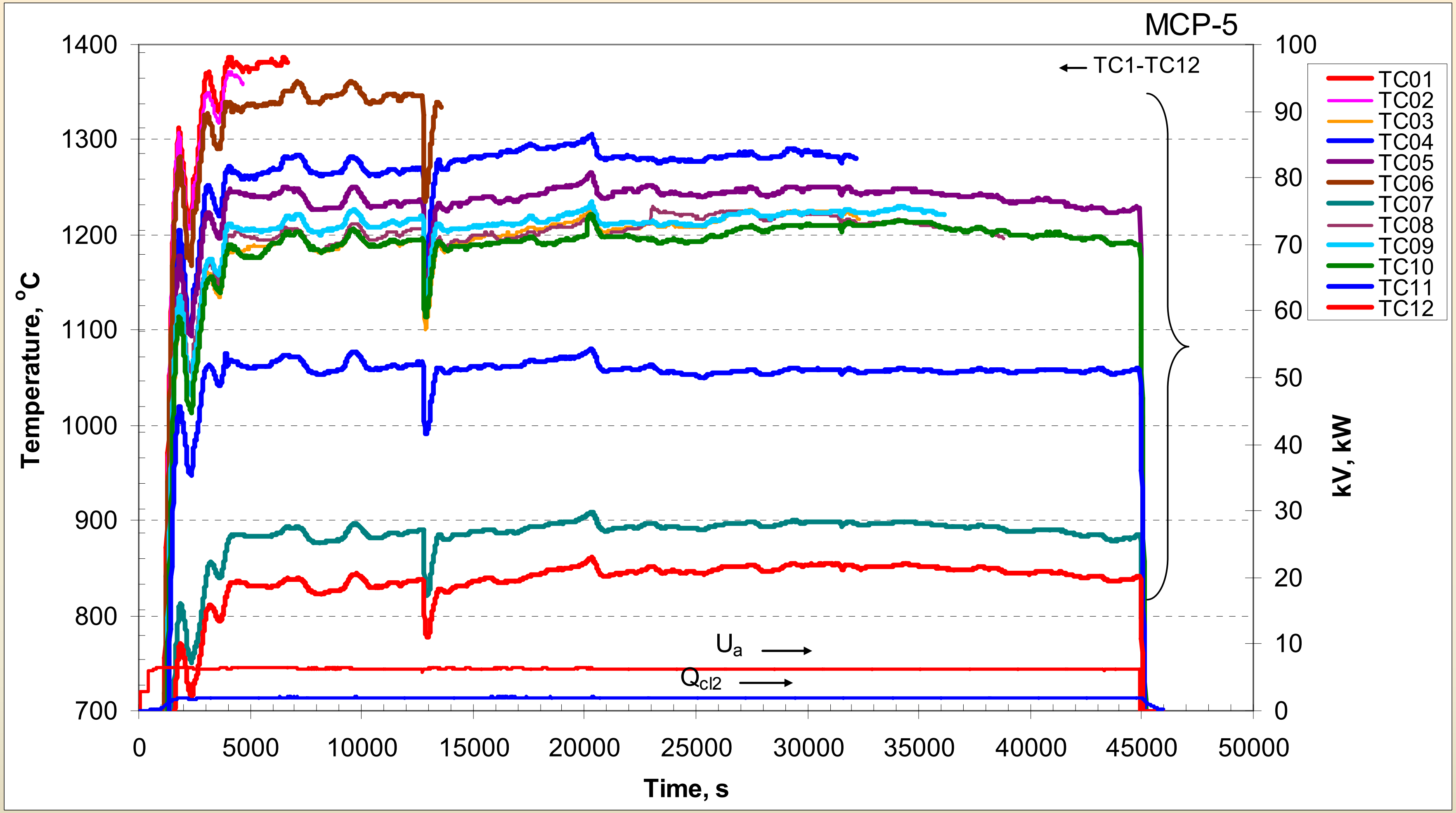



**1 – Ar tank; 2 – silica gel drier; 3 – flow-rate transducer; 4 – cyclone; 5 – LAF filter; 6 – AFA filter;**
**7 – electrochemical oxygen detector; 8 – hydro lock;**
**9,10 – vacuum pump**

# Experimental procedure

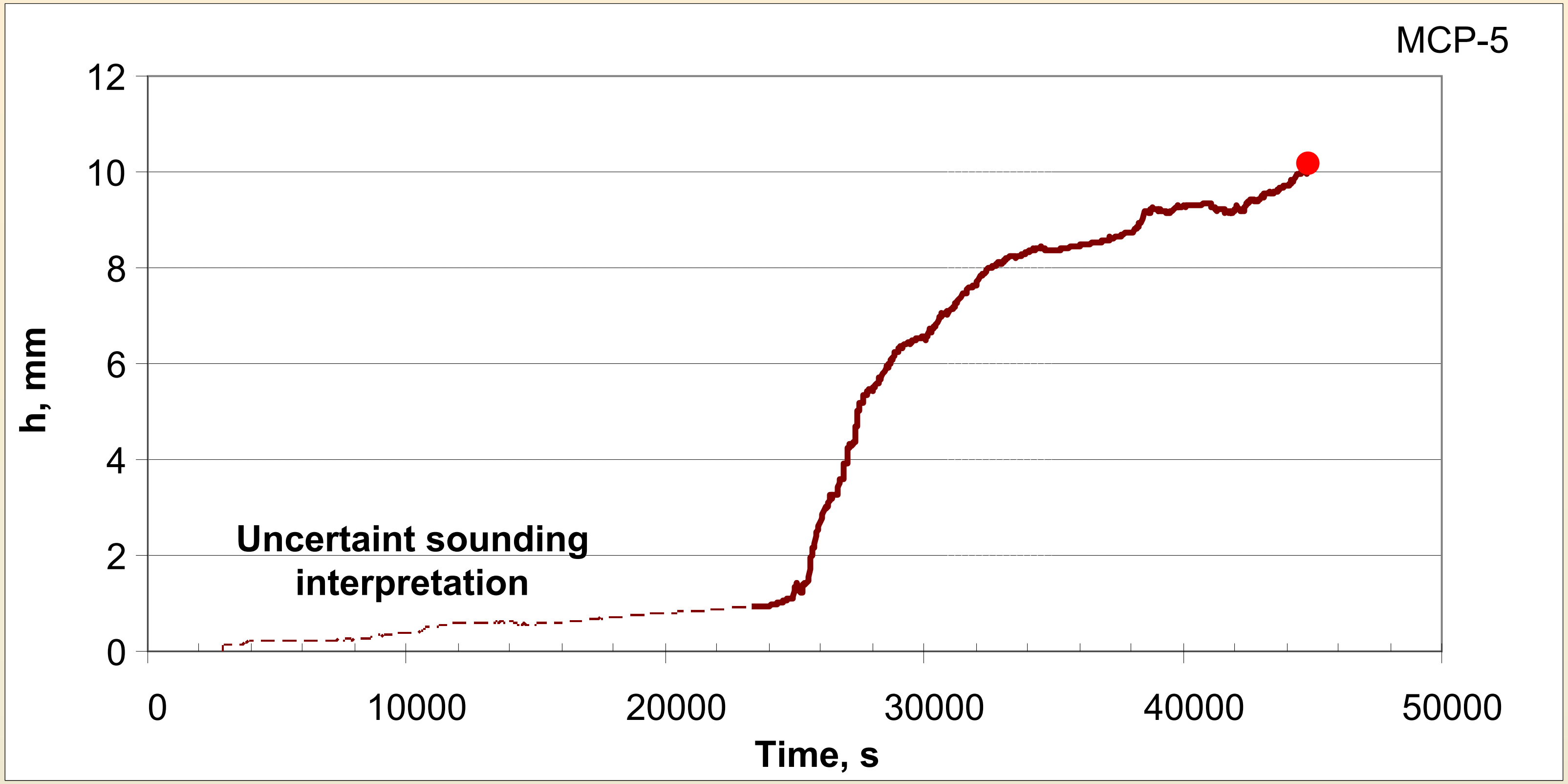
| Time, s | Description |
|---|---|
| 0 - 1870 | Startup heating in the argon atmosphere. Molten C–30 pool formation. First melt sample is taken. $T_{melt} \approx 2400°C$; $T_s \approx 1300°C$ |
| 1870 - 2610 | $U_{ind}$ adjustment; the screen is shifted to get $T_s \approx 1400°C$. $T_{melt} \approx 2400°C$ |
| 2610-44920 | Specimen temperature stabilization regime. Investigation of vessel steel corrosion kinetics at its interaction with corium through the crust in argon atmosphere. Large-area filter LAF-1 is replaced |
| 13000 | Automatic disconnection of HF heating, which was immediately reestablished |
| 13050 – 44920 | The temperature stabilization regime is in progress, it is monitored by the indications of operating thermocouples. Large-area filters LAF-2,3 are replaced. The second melt specimen is taken. |
| 44920 - 45200 | The generator is disconnected, the melt is crystallized and the ingot is cooled in the argon atmosphere |

# Specimen temperatures versus time




- ✓ **Thermocouple readings in the plot are interrupted when a TC breaks down**
- ✓ **As the heated top-level TCs break down, the stationary regime is controlled using the indications of lower and cooler thermocouples**

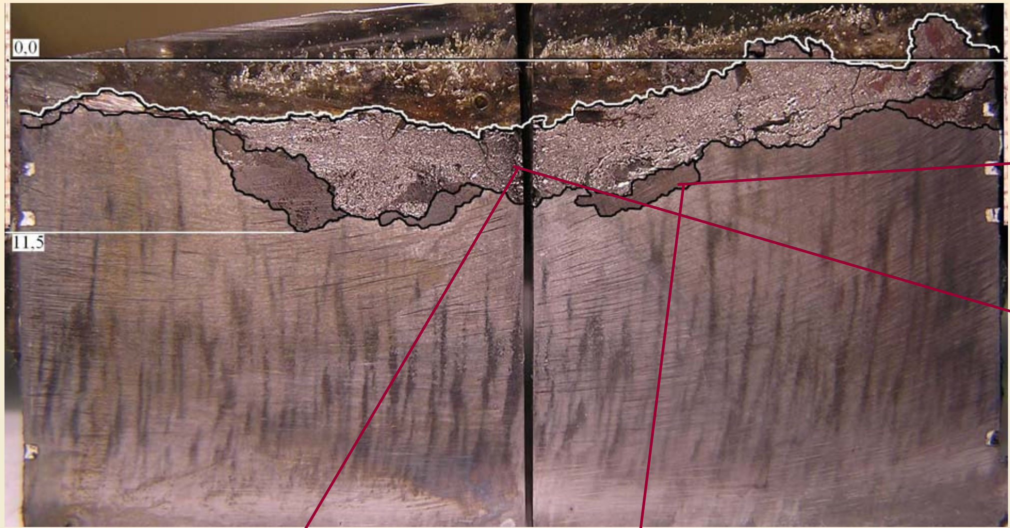
# Corrosion depth dynamics




**— – US measurement; • – Post test measurement of specimen section**

- ✓ Long incubation period - approximately 20 000 s
- ✓ Corrosion decreases as its front progresses into the specimen bulk – a lower-temperature region
- ✓ Corrosion process is not finished ?

# Specimen axial section

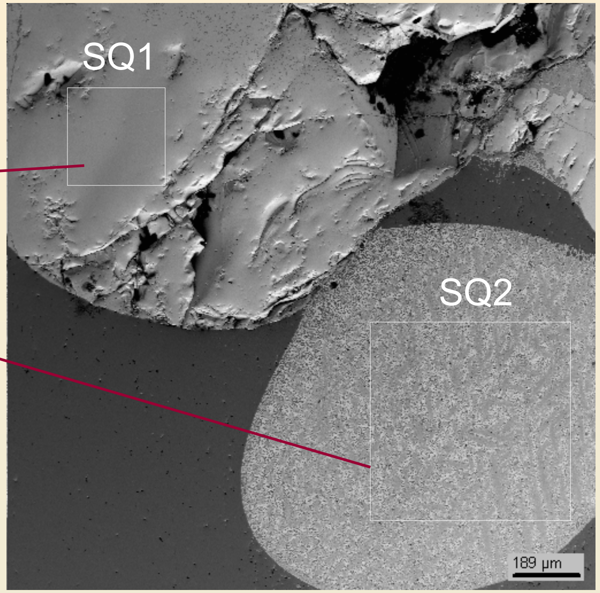



mass.%

U – 40; Zr – 16; Fe – 42

U – 38; Zr – 4; Fe – 50

SEM/EDX

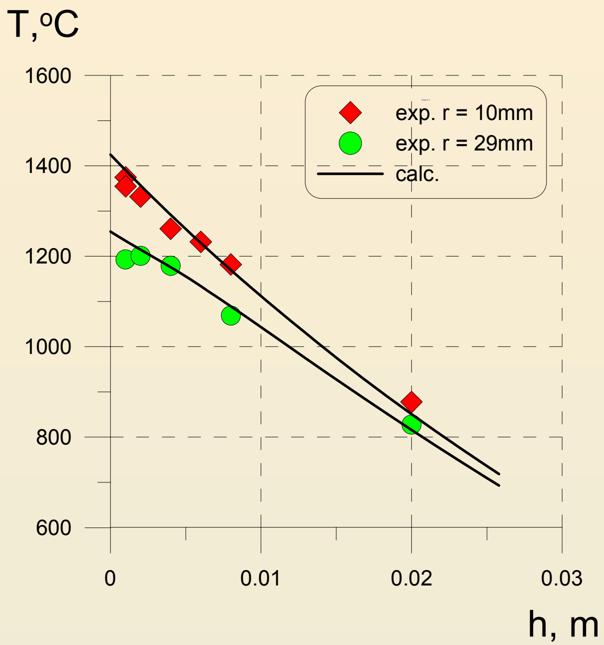


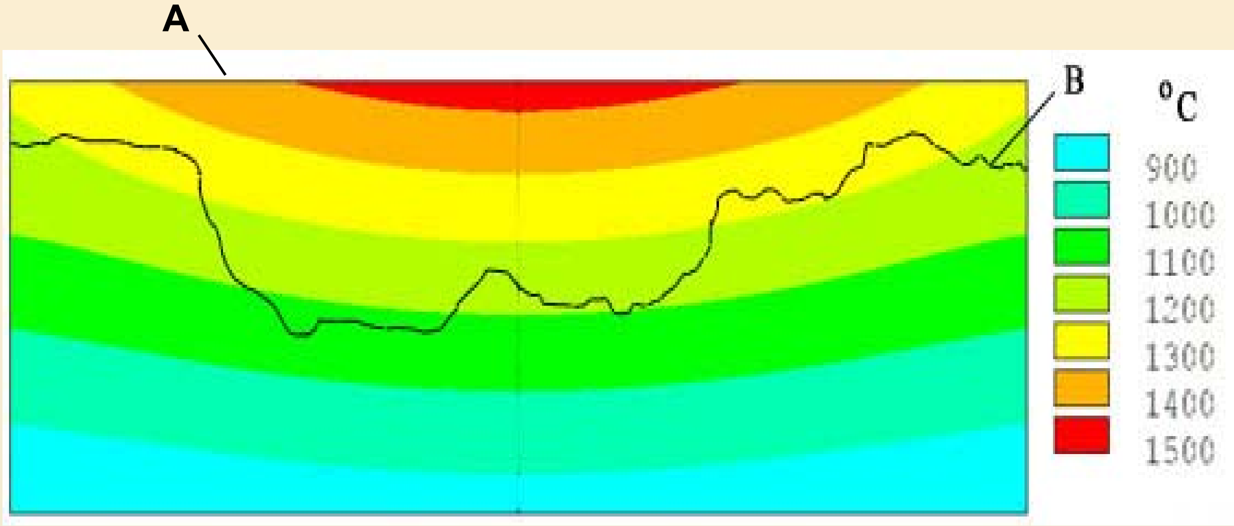

mass.%

| | U | Zr | Fe |
|---|---|---|---|
| SQ1 | 34.8 | 1.2 | 53.3 |
| SQ2 | 37.8 | 11.4 | 40.7 |

- ✓ The section is perpendicular to the ultrasonic defect axis
- ✓ Non-even boundary of the interaction zone
- ✓ 2 different structures in the IZ visible at the macrolevel

# Specimen temperature conditions and IZ final boundary position in the end of the test




- A – initial position of the specimen surface, B – final boundary of the interaction zone
- Calculated by the ANSYS code using the measured boundary conditions and temperatures in TC locations
- The IZ boundary is located in the 1060 - 1250° C temperature region

# Comparison with corrosion of Russian vessel steel

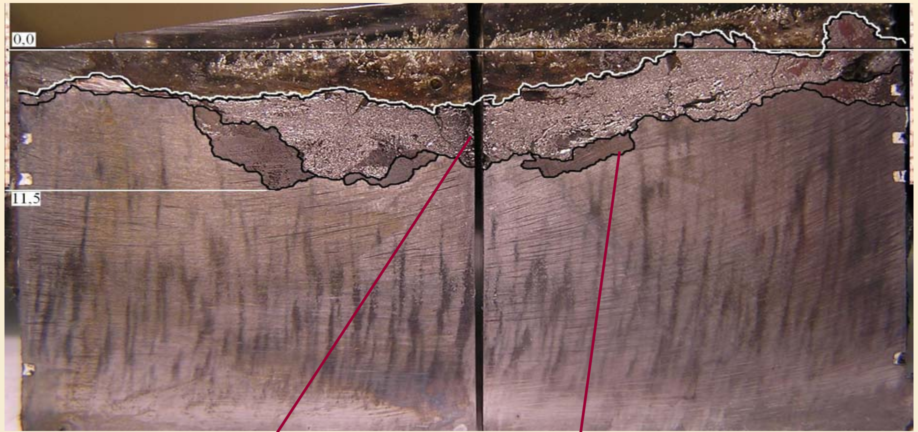
| Test | Corium oxidation index, $C_n$ | Temperature on the IZ boundary, $T_B$, °C | Mass fraction of the interacting specimen steel, $\overline{m}_{st}$ ,% | IZ composition, mass.% | | |
|---|---|---|---|---|---|---|
| | | | | U | Zr | Fe |
| MC6 * | C-30 | 1120…1200 | 4.1 | 25.6 | 5.4 | 64.4 |
| MC7 | C-30 | 1030…1100 | 0.4 | 44.0 | 2.2 | 50.0 |
| MC8 | C-70 | 1200 | 2.9 | 22.0 | 6.1 | 68.2 |
| MC9 * * | C-30 | 1060…1100 | 11.5 | 33.3 | 8.3 | 53.0 |
| MCP-1 * | C-17 | 1000…1090 | 5.9 | 44.4 | 14.0 | 40.0 |
| MCP-5 * * | C-30 | 1060…1250 | 5.6 | 40.0 | 14.0 | 44.0 |

* - metallic body in the ingot
* * - molten oxidic pool with free surface

- The crust-free pool surface guarantees the absence of “hot” metallic liquid in the oxidic liquid due to Fe evaporation
- In terms of conditions, the most similar test to MCP- 5 is MC9 ($C_n$ and the absence of crust)

# Comparison with corrosion of Russian vessel steel (2)

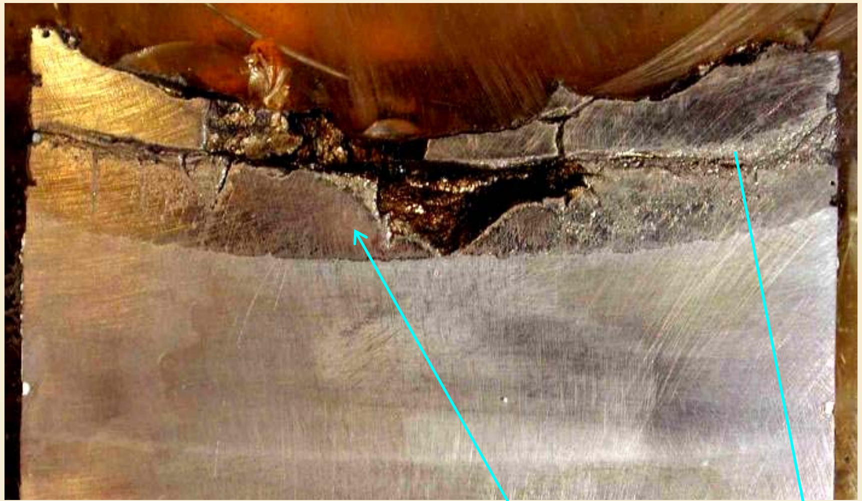
**MCP- 5**




**U – 40; Zr – 16; Fe – 42** **U – 38; Zr – 4; Fe – 50**

**mass.%**

**MC9**

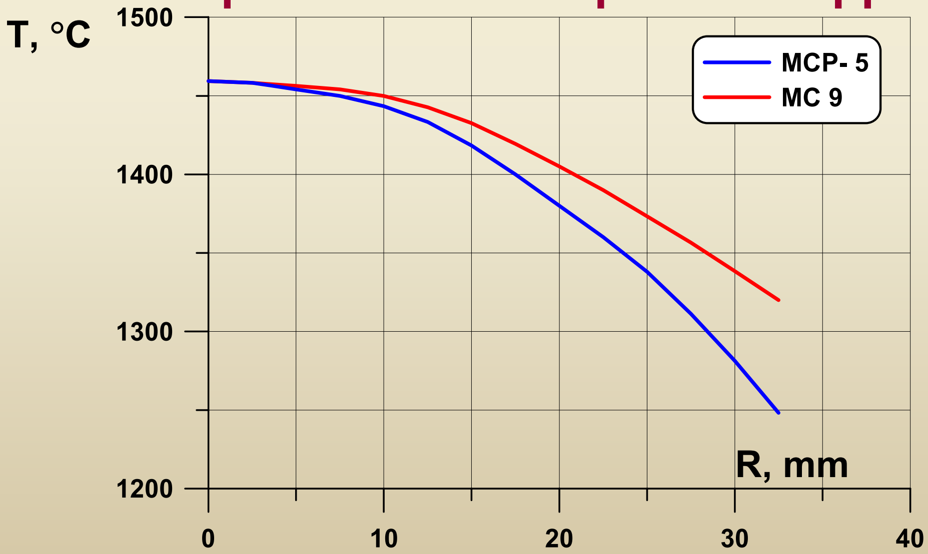


**U – 27.0**
**Zr – 11.0**
**Fe – 56.0**

**U – 39.5**
**Zr – 5.4**
**Fe – 50.0**

**mass %**

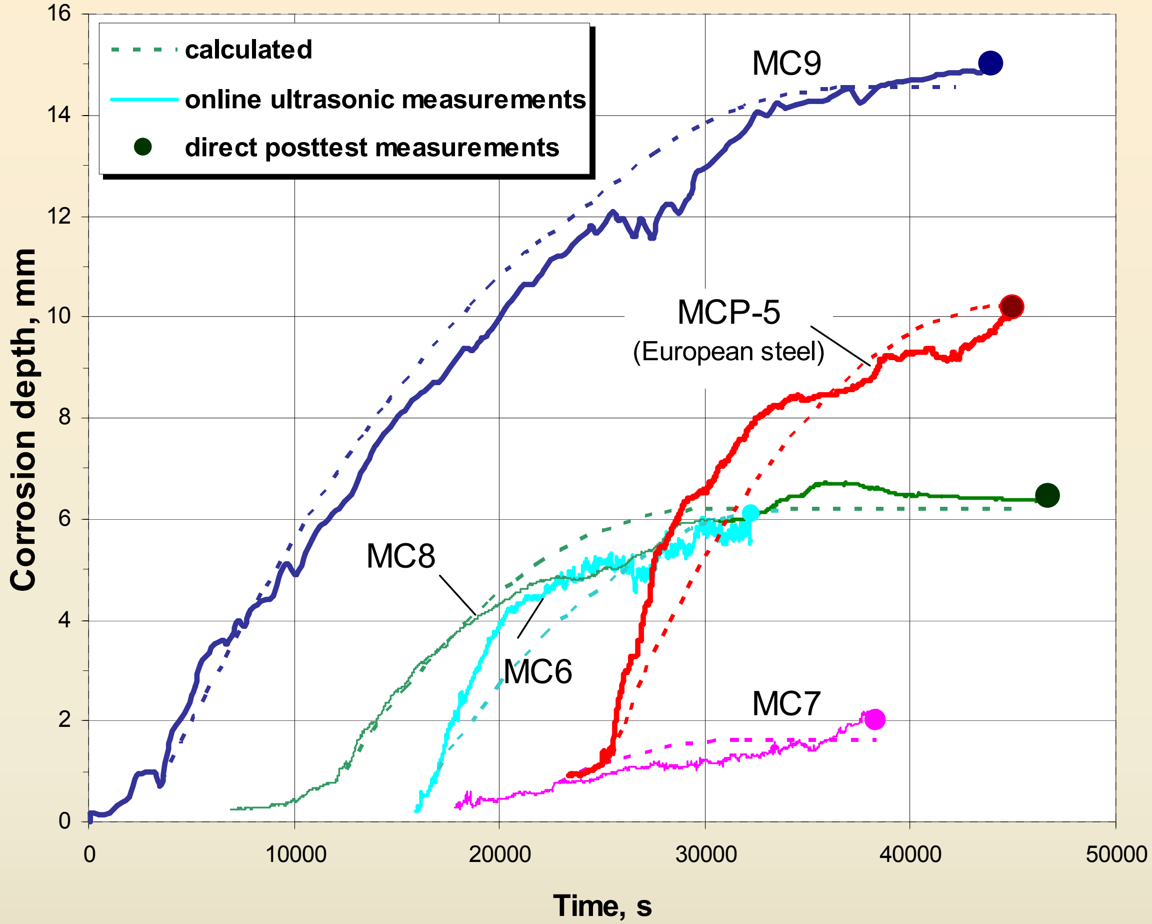
**Temperature at the specimen upper top**



# Comparison with corrosion of Russian vessel steel (3)

| | MCP-5 | MC9 |
|---|---|---|
| IZ structure | 2-layer, no uniform | 2-layer, ordered |
| Corrosion depth along the specimen axis, mm | 10 | 15 |
| | Consequences of differences in the specimen temperature condition | |
| Fe fraction in IZ, mass. % | 44 | 53 |
| | Consequences of different mass of dissolved Fe | |
| Temperature at the final IZ boundary, °C | 1060…1250 | 1060…1100 |
| | Consequence of no process saturation? | |
| Incubation time, s | 20000 | 600 |
| | Metal melt in the pool bottom layer in MC9 | |

# Comparison with corrosion of Russian vessel steel (6)




## Correlations for corrosion rates

**Russian steel ( generalization of 4 tests)**

$$(1)\quad \frac{dh}{dt} = 0.46 \cdot 10^{-4} \sqrt{T_{int} - T_B}, \quad mm/s$$

**European steel (1 test)**

$$(2)\quad \frac{dh}{dt} = 0.66 \cdot 10^{-4} \sqrt{T_{int} - T_B}, \quad mm/s$$

# Conclusions

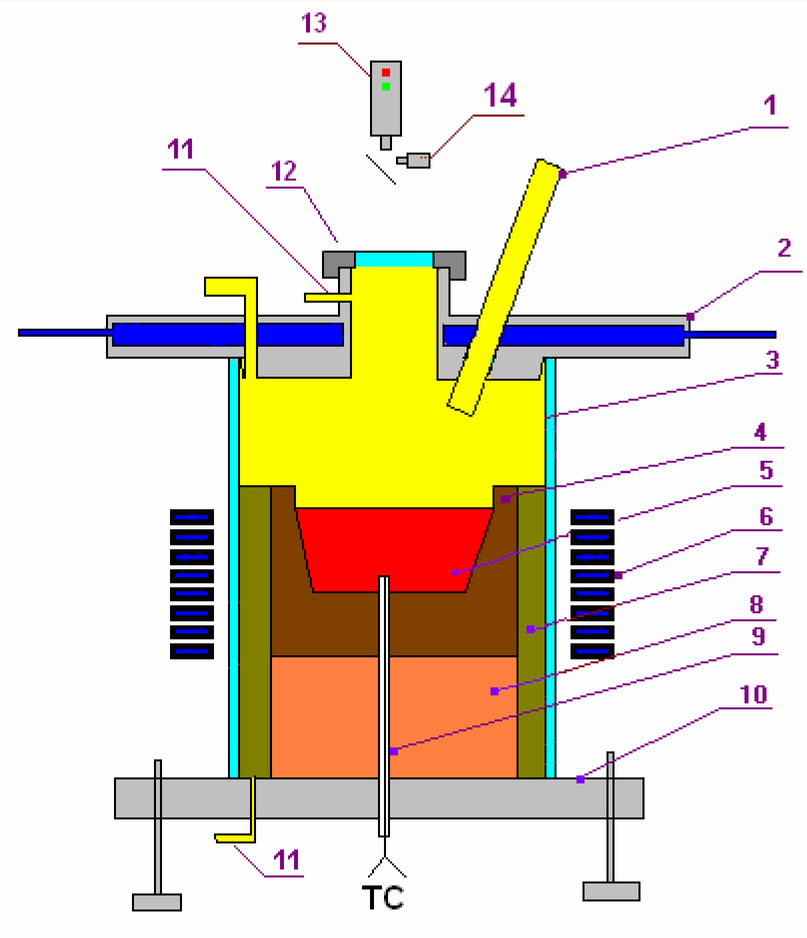
- Qualitative and partially quantitative agreement in corrosion results for the European and Russian vessel steels at the interaction with suboxidized molten corium
- The irregular structure of IZ and the large scattering of the final temperature of the IZ boundary may be due to the lack of process saturation
- A single test wit the European steel is insufficient for a more comprehensive analysis and model development

# Oxidation of the uranium-containing metallic melt in steam. Test MCP-6

## Objectives

**Study of oxidation kinetics of the U- and Zr-containing metallic melt through the oxidic surface crust after neutral atmosphere replacement by steam**

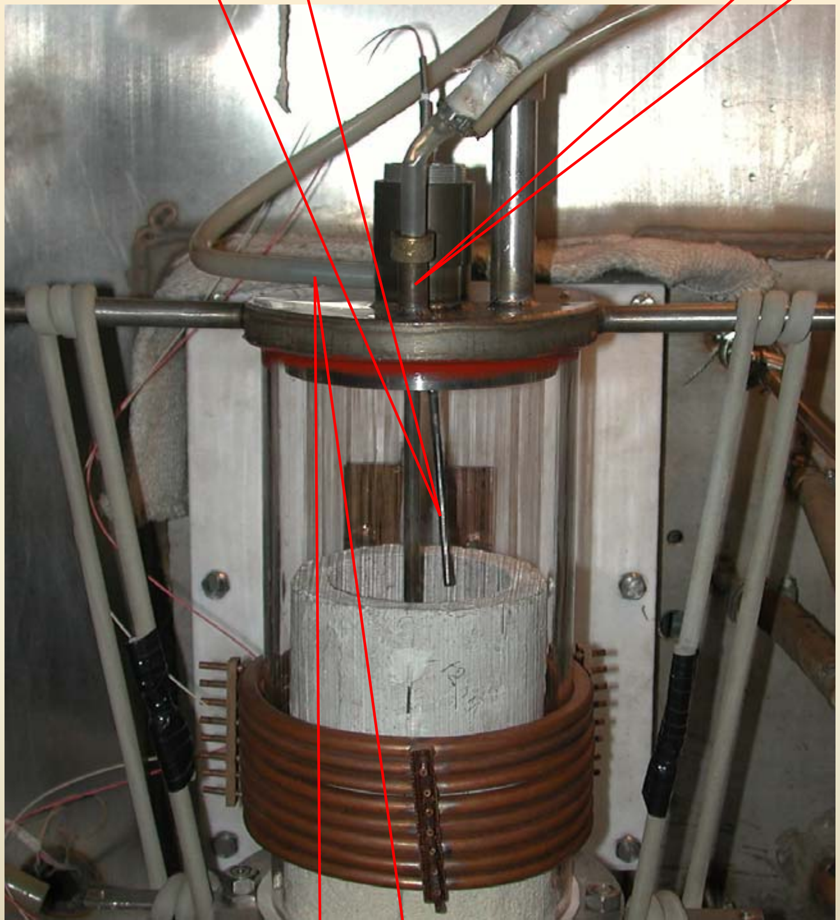
# Furnace schematics

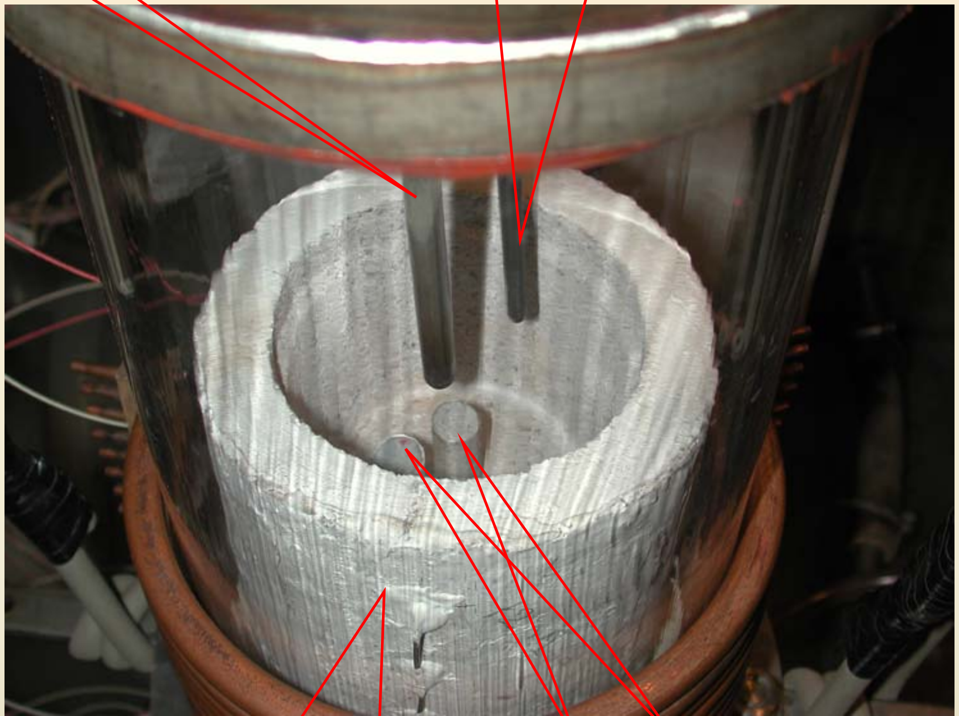



- **Crucible (4) was made of $ZrO_2$ concrete**
- **To prevent melt oxidation through crucible walls, its outer surfaces were coated with alumosilicate binder with $ZrO_2$ filling.**
- **The crucible outer surface was separated from the water-cooled inductor with thermal insulation (7)**
- **To reduce steam condensation on the water-cooled furnace cover (2), its thickness was increased**
- **The molten pool surface was located at the crucible upper top**
- **The furnace volume including thermal insulation (7) was separated from the ambient atmosphere with quartz tube (3)**

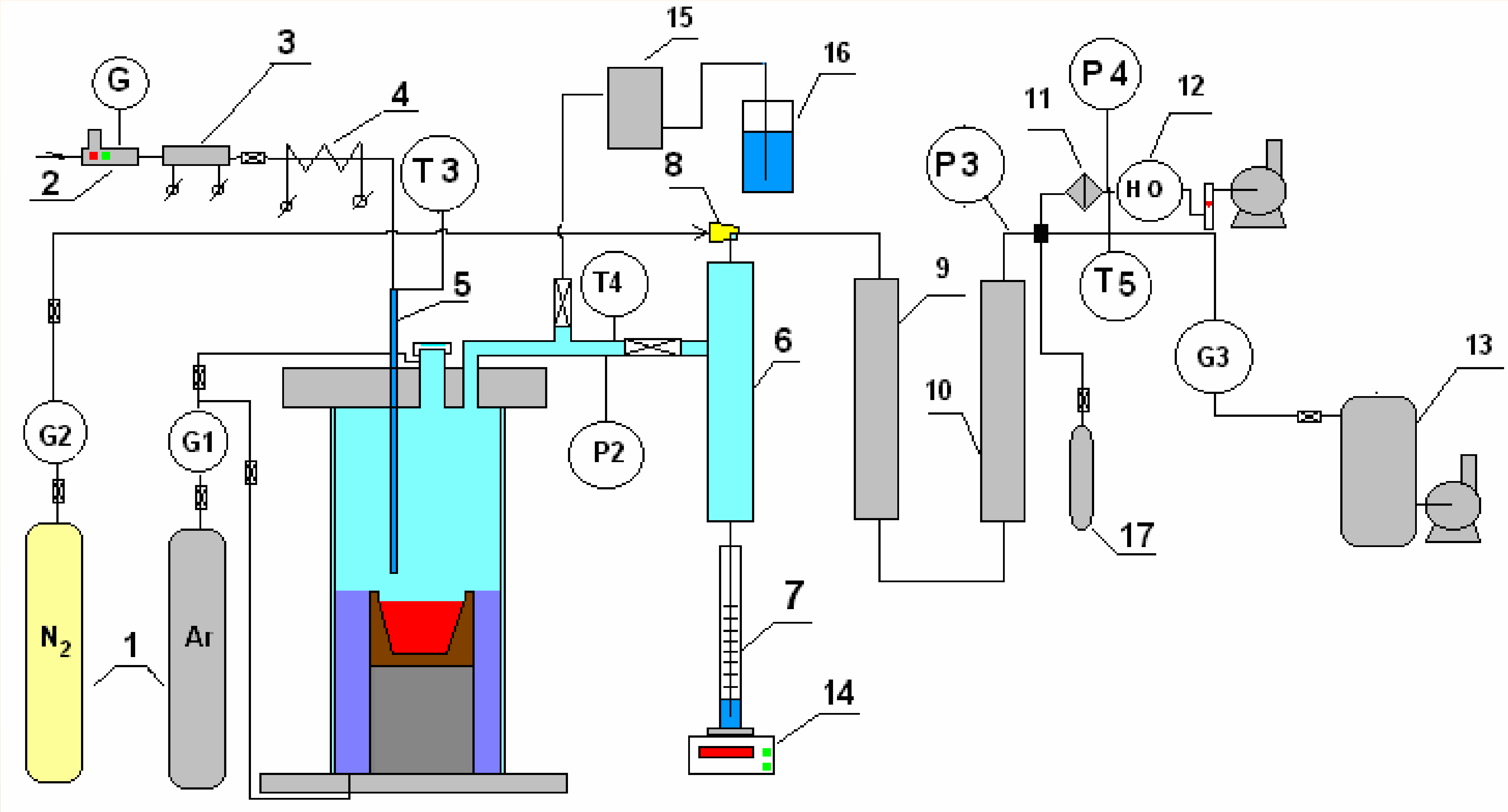
1 – two ports of corrosion-resistant tube: for steam supply and for the introduction of W/Re thermocouple in a tungsten sheath; 2 – water-cooled furnace cover; 3 – quartz tube; 4 – crucible made of $ZrO_2$ concrete; 5 – metallic melt; 6 – inductor; 7 – thermal insulation; 8 – lightweight bottom; 9 – two W/Re thermocouples in the $ZrO_2$ sheath; 10 – corrosion-resistant bottom; 11 – Ar supply port; 12 – lid of monitoring window; 13 – pyrometer; 14 – video camera

# Furnace schematics (2)



# Gas-aerosol sampling system




1 – Ar, $N_2$ tanks; 2 – water regulator – flow rate meter to the direct-flow steam generator; 3 – direct-flow once-through steam generator; 4 – heated steam supply line; 5 – corrosion-resistant tube of steam supply into the furnace; 6 – steam condenser; 7 – condensate collector; 8 – ejector; 9 – large-area filter (LAF); 10 – silica gel dehumidifier; 11 – Petrianov filter (AFA); 12 – electrochemical sensors of $O_2$ and $H_2$; 13 – vacuum receiver; 14 – tensiometric weight sensor; 15 – medium-area filter (MAF); 16 – hydrolock

# Crucible charge

| Component | **Mass, g** |
|---|---|
| SS: 08Kh18N10T | 1475 |
| U | 487 |
| Zr | 324 |
| **Total mass** | **2286** |

# Experimental procedure

1. 0…560 s – furnace deoxygenation by argon
2. 560…6550 s – smooth heating up, charge melting, melt heating up to ≈1500°C
3. 6550…6800 s – Addition of metallic zirconium into the melt followed by the melt exposure, monitoring of the melt temperature condition
4. 6800…9700 s –cleaning of the melt surface from crust
5. 9700 s – steam supply into the furnace at 103 g $H_2O$/hr, start of melt oxidation (melt temperature within 1380 – 1580°C), steam-gas mixture sampling into vacuum burettes
6. 9900 s – crust surface temperature measurement by the Pt/PtRh thermocouple
7. 10696 s – registration of the beginning of condensate accumulation in the collector
8. 16200 s – an increase in steam flow rate up to 197 g $H_2O$/hr
9. 20037 s – steam supply replacement by argon
10. 22036 s – HF heating disconnection after the concrete crucible drying

# Surface view during the test

**Molten pool preparation, 5000 s**

**Beginning of the oxidation, 10000 s**

**Thick crust with cracks, 20000 s**

**Melt crystallization, 25000 s**

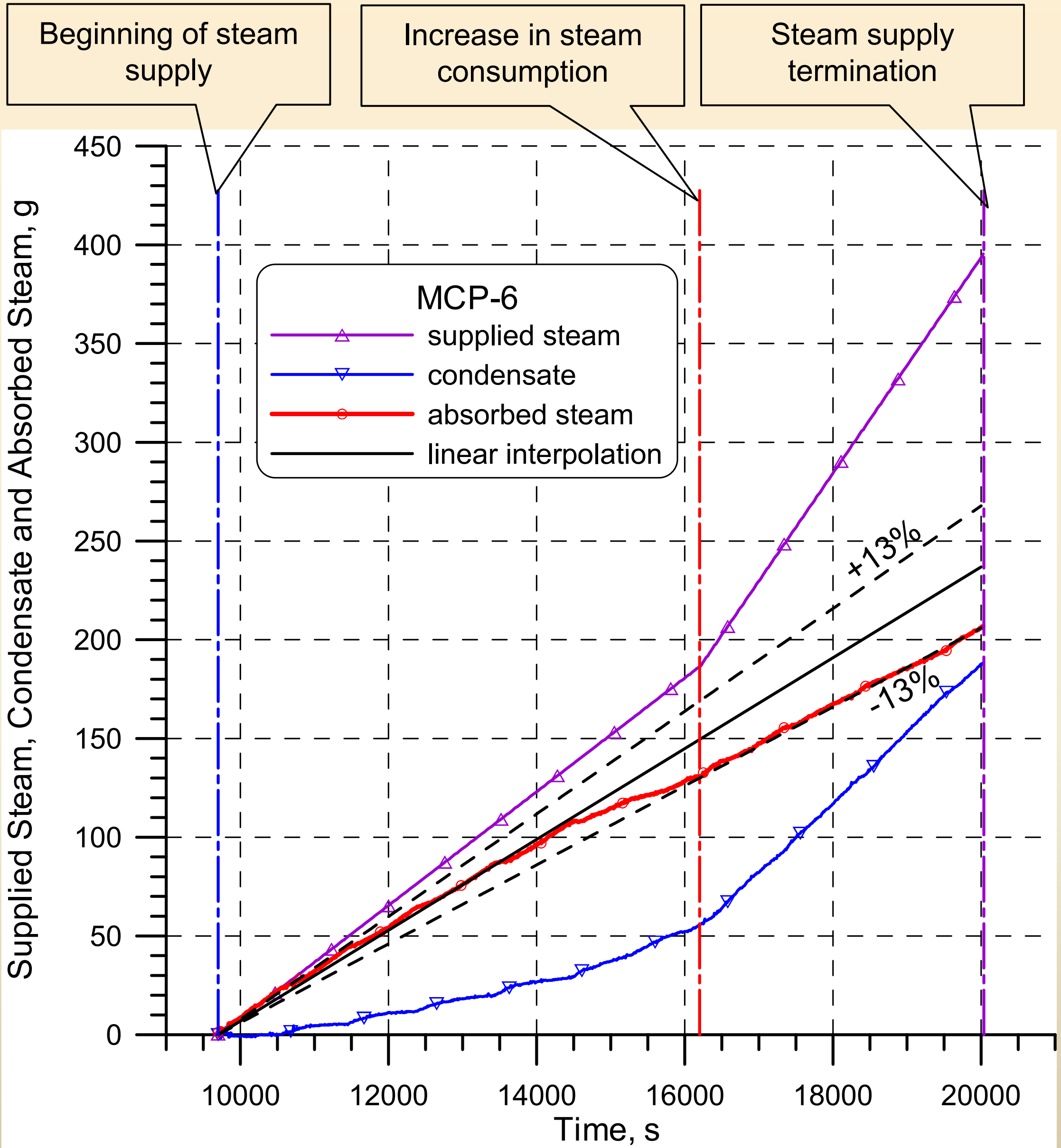
# Post-test analysis (in progress)

**Crucible and oxidic crusts cross-section**

- No visible crucible walls erosion
- Crust thickness:
  upper surface – 5…6 mm,
  lateral – 3…4 mm,
  bottom – about 2 mm
- Metallic inclusions in crucible walls

Metallic inclusions

# Post-test analysis (2)




**Steam absorption calculated from steam/condensate balance**

- Oxidation of the melt by steam can be fairly well approximated by the linear interpolation with the steam absorption rate which equals

**23 (±3) mg $H_2O$/s**

- Some decrease in the oxidation rate was observed at the beginning of steam supply (until 16200 s) when the oxidic crust growth occurred

# Primary Conclusions

✓ Even in the relatively small scale experiments the oxide crust on the metal melt surface is found to be broken

✓ Linear dependence of absorbed steam mass (oxide crust thickness) versus time can be explained by:

- **Steam starvation regime (absorption of all steam and evacuation of all hydrogen from the crust surface) in the test conditions**

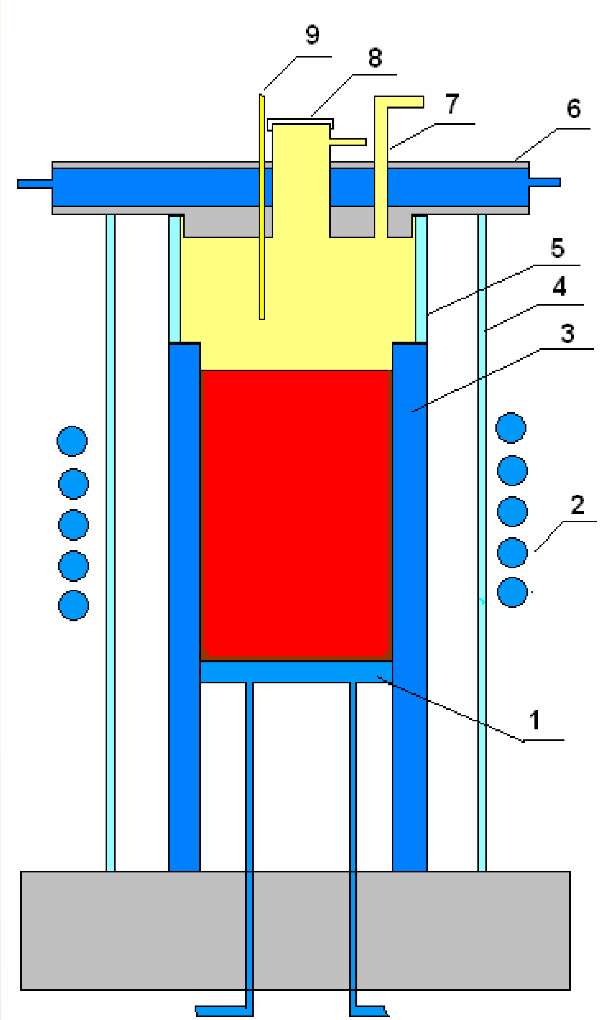
- **Lack of crust integrity**

# Oxidation of suboxidized corium melt in steam. Test MCP-7

## Objectives

**Study of oxidation kinetics of the suboxidized molten pool through surface oxidic crust after neutral atmosphere replacement by steam**

# Furnace schematics




**Measures to reduce steam condensation:**

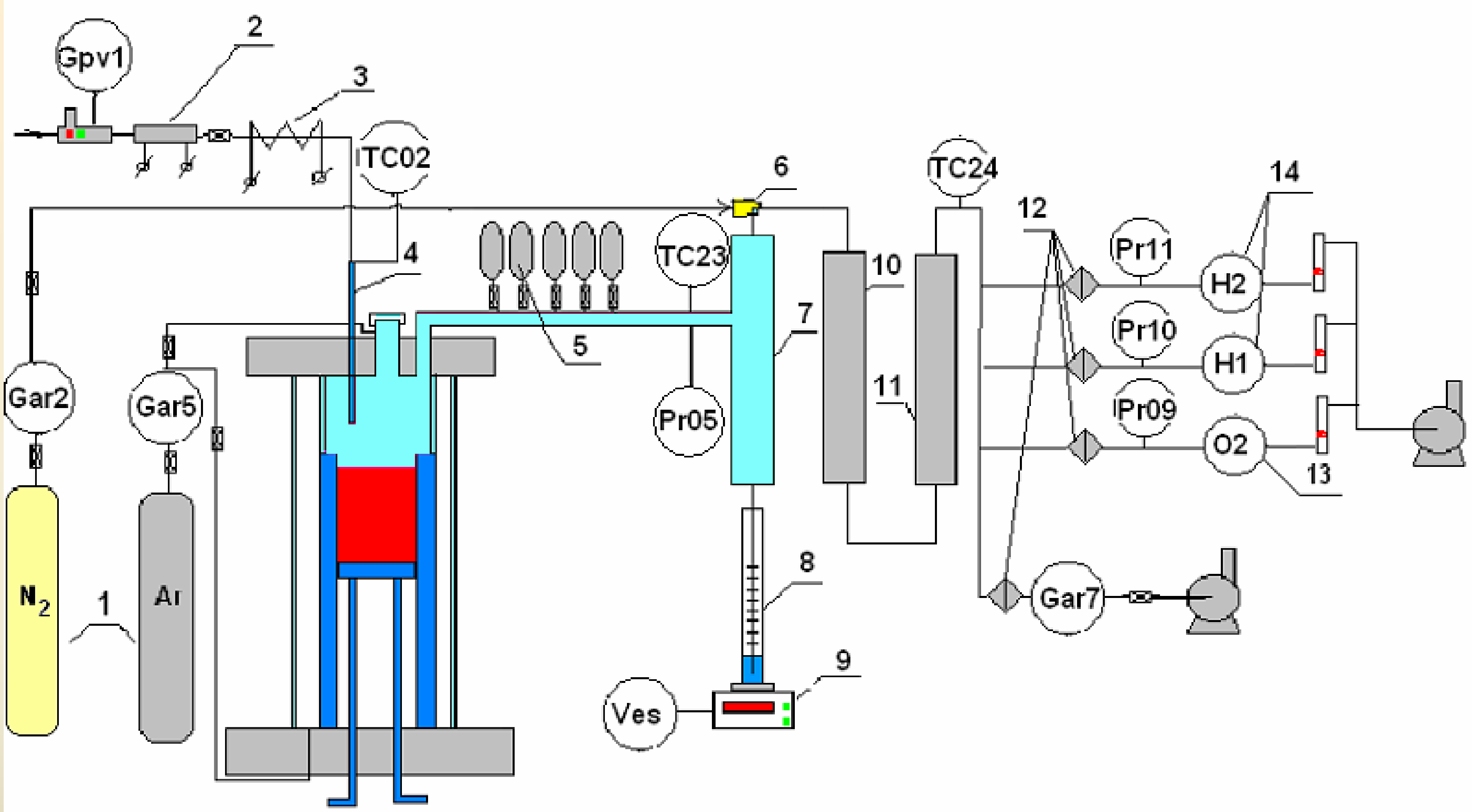
- **rise of melt surface to the crucible top**
- **separation of above-melt volume from the furnace volume by quartz tube (5)**
- **seal of the gaps between cold crucible tubes**
- **increase of thickness of water-cooled furnace cover (6)**

**To suppress meniscus the melt surface was moved above the top inductor**

**To form the oxidic crust the melt surface temperature was reduced**

1 – water-cooled bottom calorimeter; 2 – inductor; 3 –water-cooled crucible; 4 – quartz tube; 5 – quartz ring; 6 – water-cooled furnace cover with down-looking hot surface; 7 – gas-aerosol out; 8 –observation port; 9 – steam supply pipe

# Gas-aerosol sampling system




1 –Ar, $N_2$ tanks; 2 – direct-flow once-through steam generator; 3 – heated steam supply line; 4 – stainless steam supply pipe; 5 – vacuum burettes; 6 – ejector; 7 – steam condenser; 8 – condensate collector; 9 – tensiometric weight sensor; 10 – large-area filter (LAF); 11 – silicagel dehumidifier; 12 –Petrianov filter (AFA); 13–14 electrochemical sensors of oxygen and hydrogen

# Crucible charge

| Component | Mass, g |
|---|---|
| $UO_2$ | 772.5 |
| $ZrO_2$ | 94.0 |
| Zr | 147.9 |
| **Total mass** | **1014.4** |

**C-32, U/Zr = 1.2**

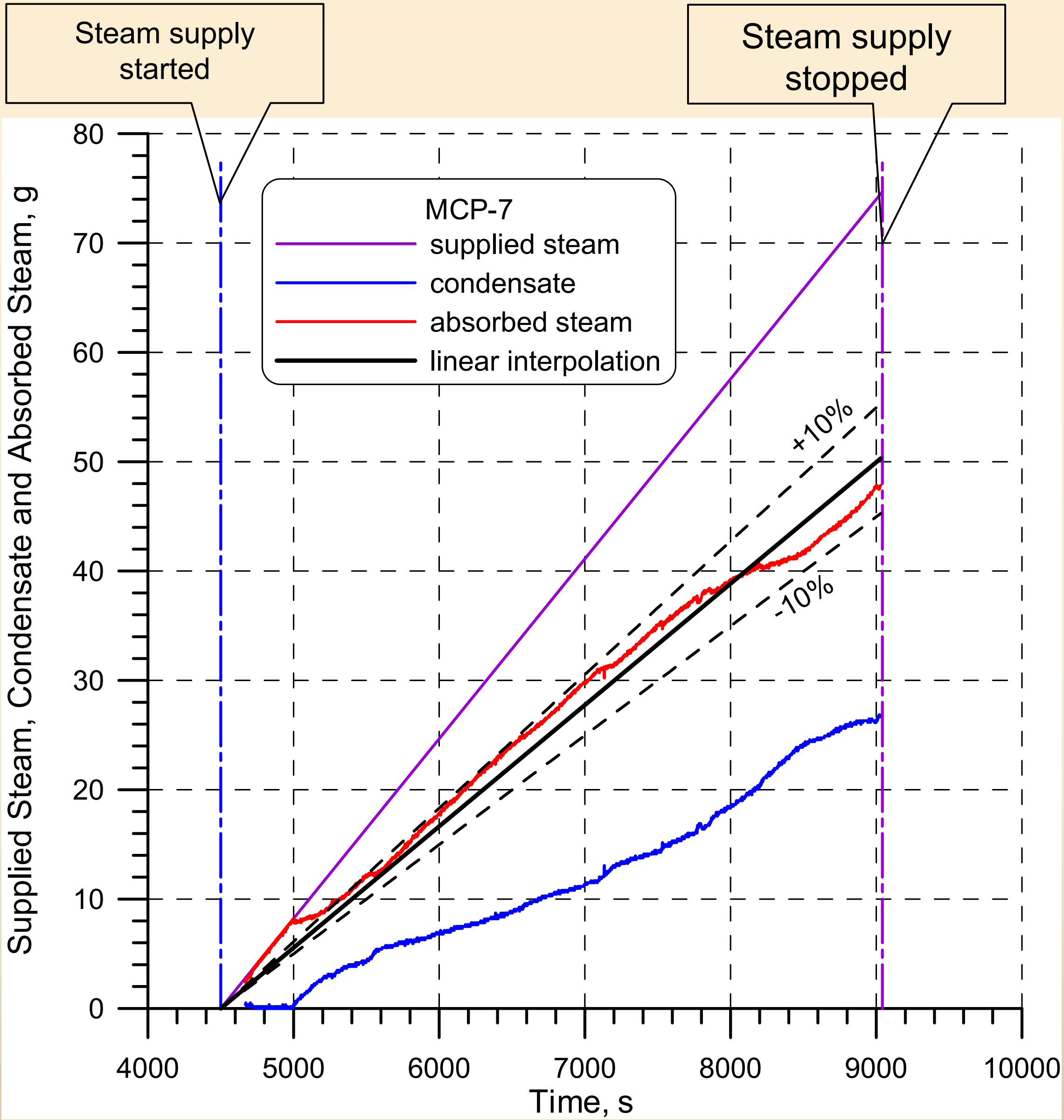
# Experimental procedure

1. 0…190 s – furnace deoxygenation by argon
2. 190… 3586 s – gradual heating, charge melts, the pool is formed
3. 3586…4500 s – crust is formed on the surface, its temperature is 2030°C
4. 4500 s – steam is supplied into the furnace at the flow-rate of 59.2 g $H_2O$/hr; melt oxidation starts. Steam-gas mixture is sampled into vacuum burettes.
5. 4800 s – readings of hydrogen sensor gradually go up
6. ≈5000 s – readings of condensate weight sensor go up
7. 4998, 5236, 5296, 5395, 5521, 5811 s – flow-rate of carrier gas is adjusted
8. 5911…7860 s – carrier gas flow-rate is steady, at this $H_2$ concentration in furnace gases shows instability; cracks on the oxidic crust surface appear and disappear
9. 7900…8319 s – sharp increase in $H_2$ concentration followed by the carrier gas regulation
10. 8134…8507 s – decrease of $H_2$ content in furnace gases
11. 8935 s – sharp increase of $H_2$ content accompanied by the observed crust bulging and crumbling
12. 9042 s – steam supply is replaced by argon
13. 9479 s – HF heating is disconnected, ingot is frozen.

# Crust surface after experiment

• Crust irregularity, its mechanical weakness, melt ejections and spillages observed during the test, as well as its bulging, testify to a large number of pores and cracks in the crust, i.e. to its permeability

# Post-test analysis (3)




- Melt oxidation by steam is rather well approximated by the linear interpolation with the steam absorption rate equal to **11 (±1) mg $H_2O$/s**

# Primary Conclusions

• Kinetics of suboxidized corium melt oxidation by steam through the crust is described by the linear law with the steam absorption rate of **11 (±1) mg $H_2O$/s**

• Constant oxidation rate, in spite of the growing crust thickness, testifies:

- oxidant starvation regime in the test conditions

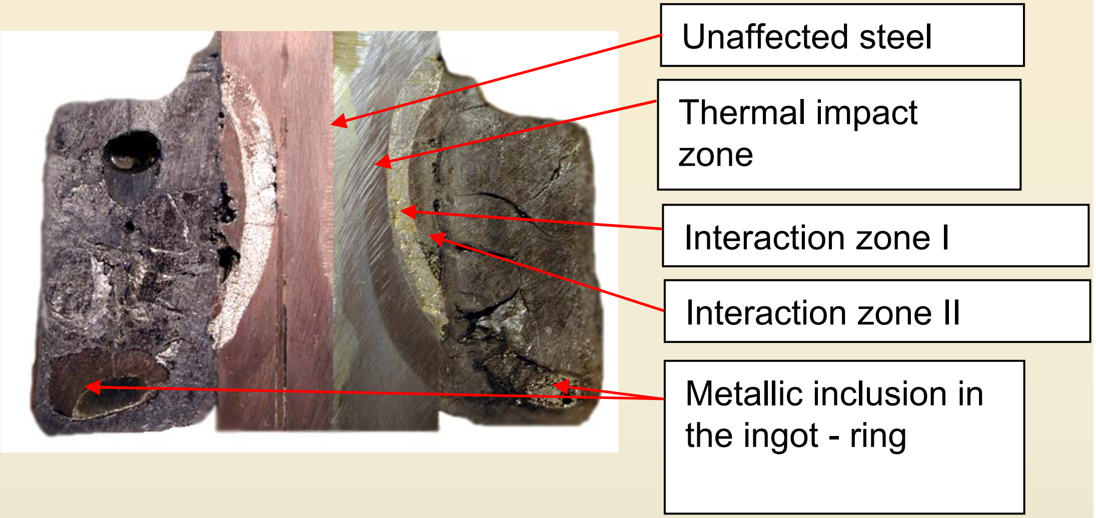
- influence of crust cracking

• Formation of cupola-shape crust with the gap between the crust and the melt surface can be explained by mechanical loads from the forming crystallites or/and gas (hydrogen?) release from the melt surface

# Preparation of Test MCP-8 on the interaction of metallic melt with vertical specimen

# Test MCP-1

**Test MCP-1 (2007): Study of vessel steel corrosion at its interaction with molten suboxidized corium**




**Main MCP-1 differences from the tests with horizontal interaction interface (prototype test of MC6):**

- Considerably shorter incubation period (or completely absent)
- Different structure and composition of the interaction zone

**Main problem during MCP-1 and posttest processing of its results: No data on steel corrosion kinetics during the test**

# Objectives of test MCP-8

**Determine corrosion kinetics of vertically positioned vessel steel specimen at its interaction with Fe-Zr-U melt**

**Method for determining kinetics:**
**On-line US monitoring of steel corrosion**

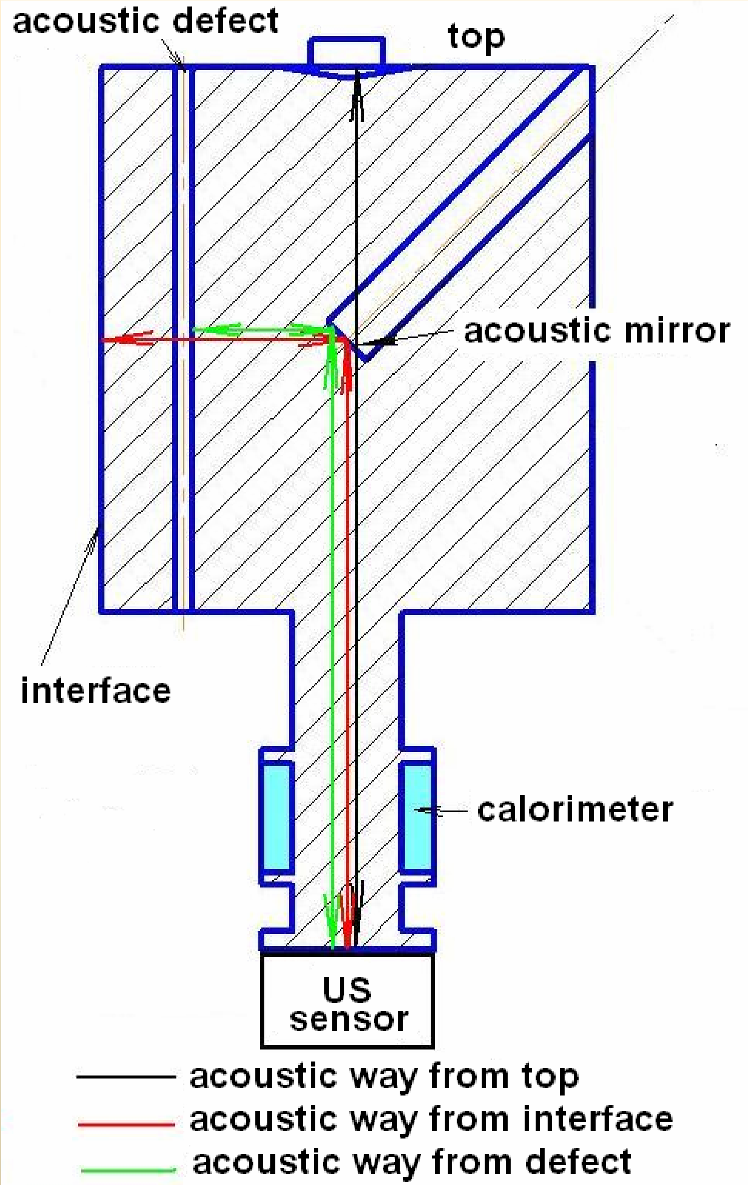
# Objectives of pretest Pr1-MCP-8

**Check the efficiency of the vertical specimen cooling systems and US monitoring**

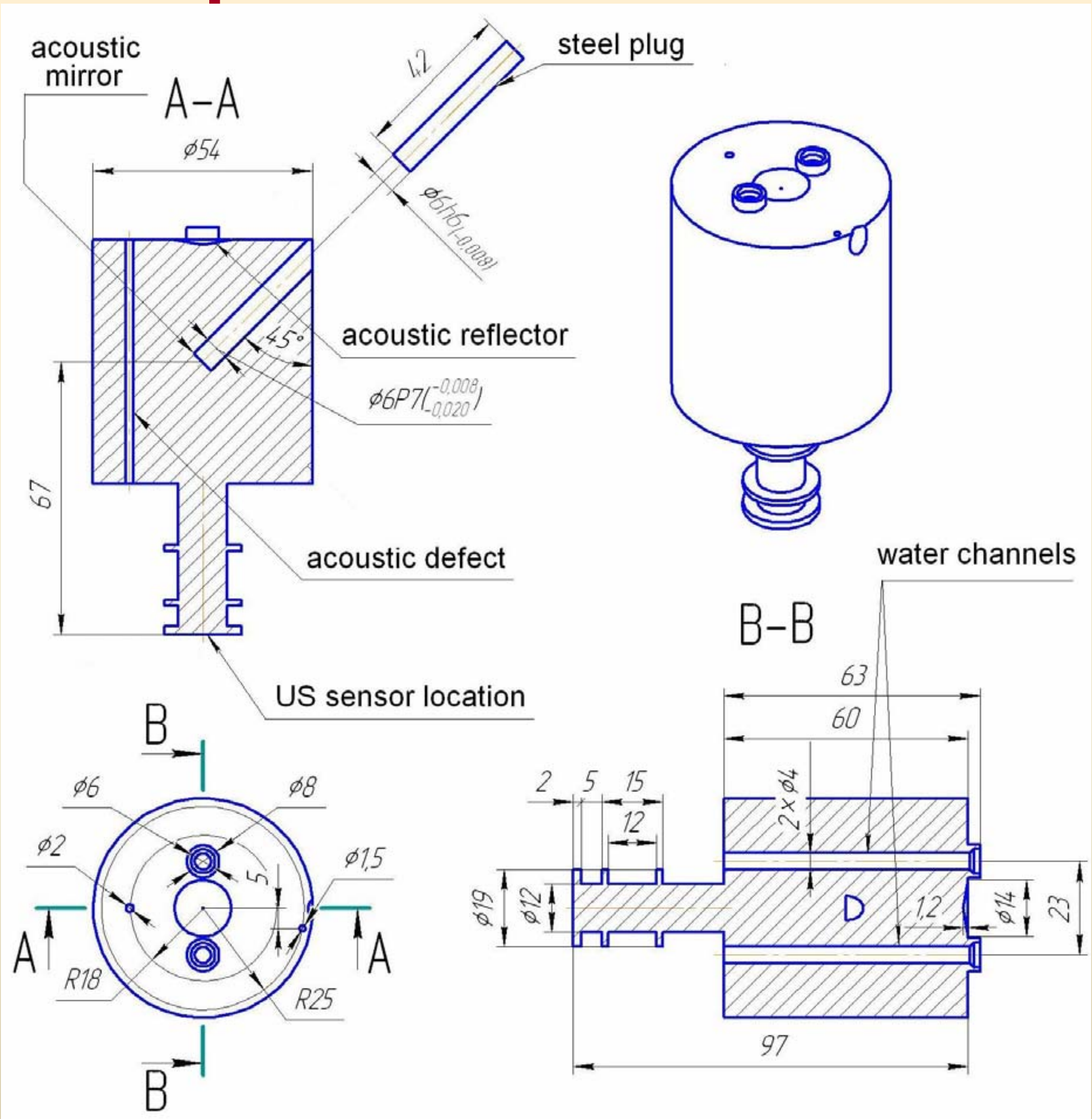
**Controlled conditions and parameters:**

- no DNB water cooling in the central channel of the specimen
- depth of ablation/melting of the outer specimen surface

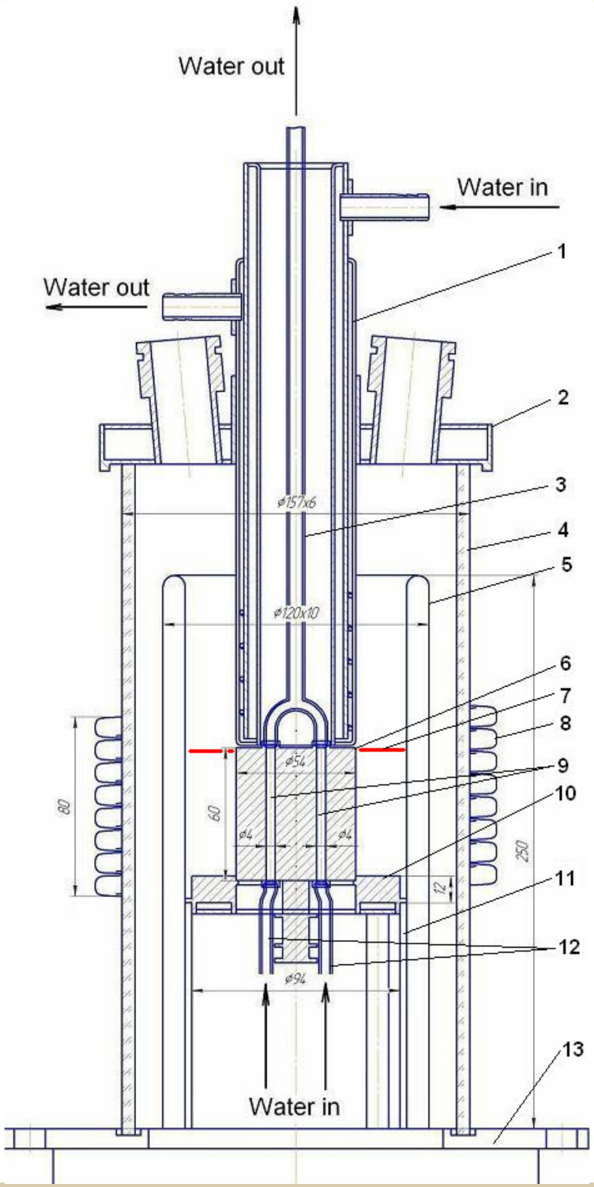
# Principle of US monitoring



# Specimen schematics



# Furnace schematics




1 – water cooled screen
2 – water cooled cover
3 – water-off pipe
4 – quartz tube
5 – crucible sections
6 – specimen
7 – melt surface position
8 – inductor
9 – two cooling channels
10 – bottom calorimeter
11 – CC holder
12 – water supply pipes
13 – furnace basis

# Modeling of specimen cooling

**Approximations:**

- stationary conditions
- 2D geometry (radius and azimuth angle) with uniform distribution of heat flux on specimen surface
- temperature dependence of vessel steel heat conductivity
- CHF Lookup Table of Groeneveld & Kirillov (1997)

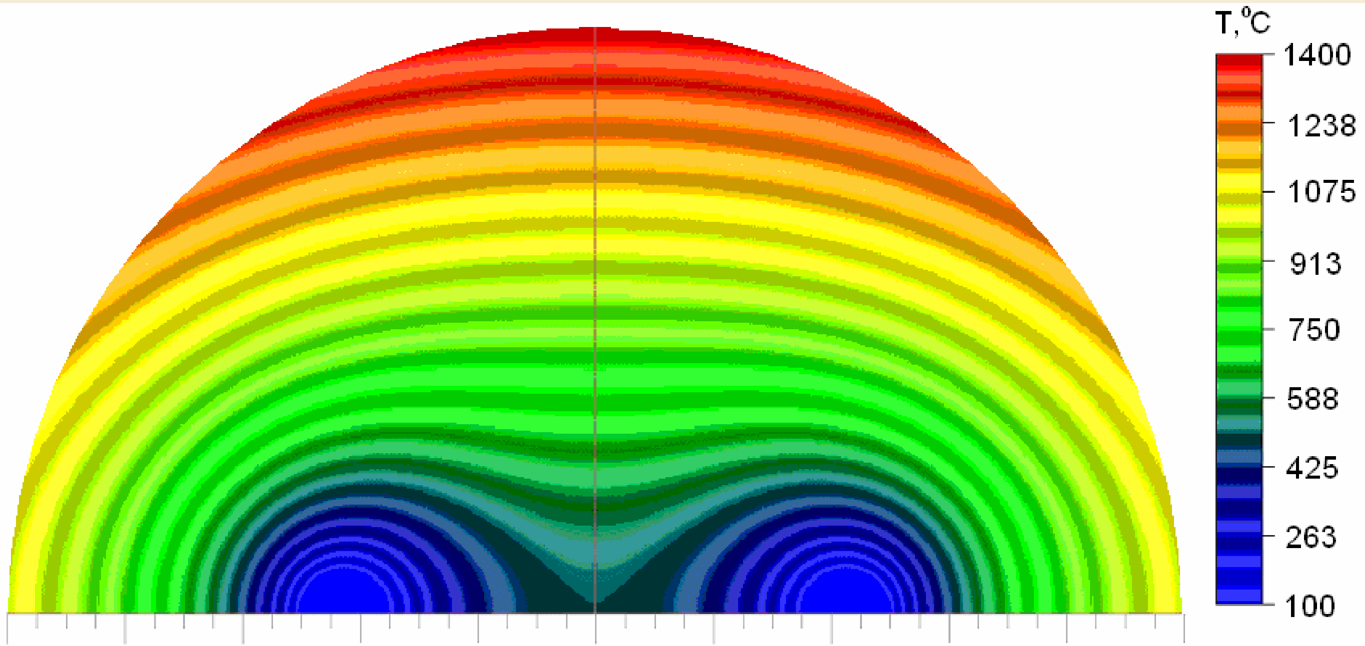
**Evaluated parameters:**

- specimen diameter – 54 mm
- diameter of water channels – 4 mm
- length of specimen – 60 mm
- water volumetric rate – 2.8 $m^3$/hr *(velocity ≈ 31 m/s)*
- outlet water pressure – 1 bar
- inlet water temperature – 20°C
- maximum surface temperature – 1400°C
- temperature of surface of water channels – 100°C

# Modeling of Specimen Cooling (2)

**Calculation results:**

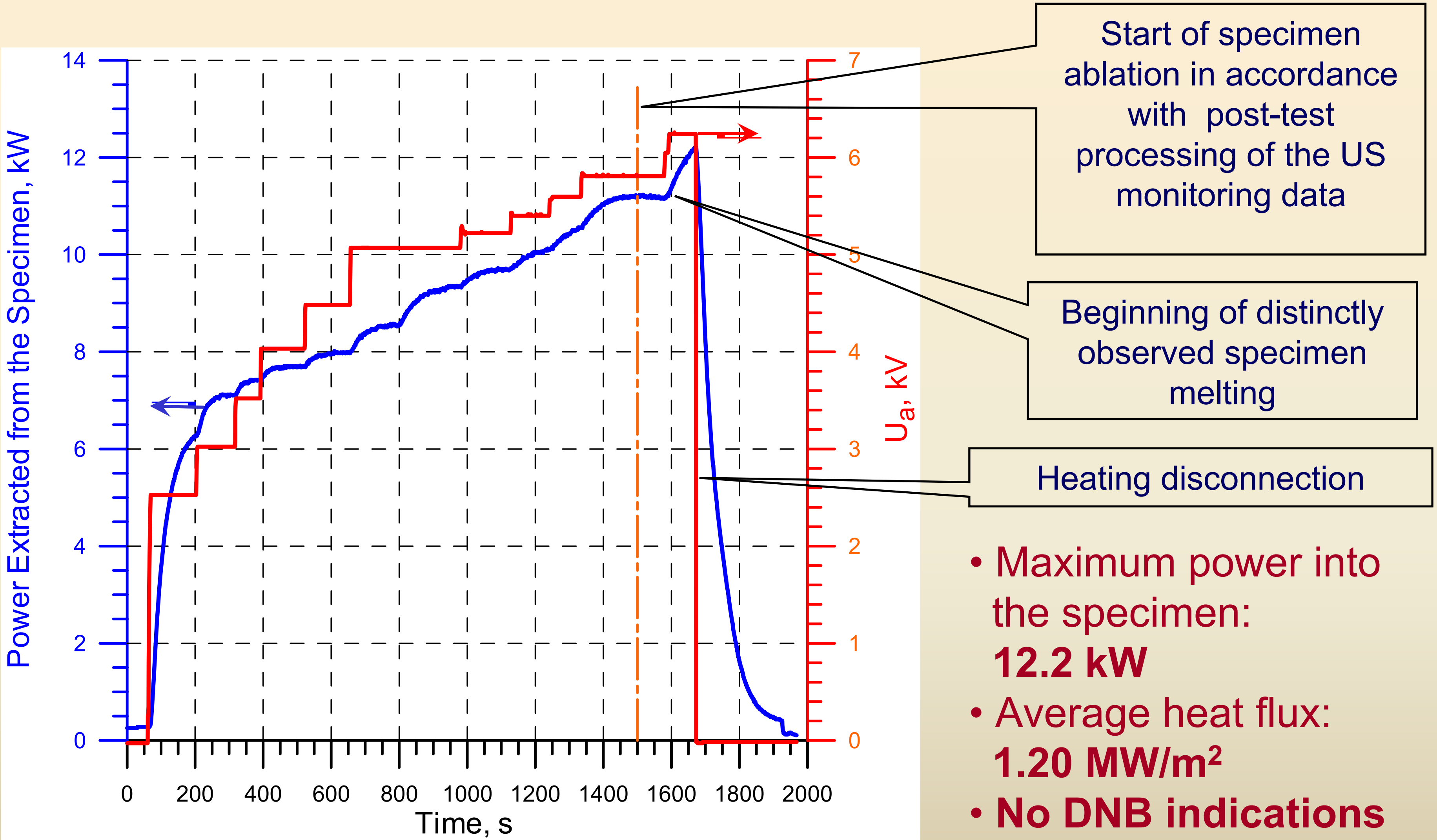
- outlet water temperature – 23°C
- power extracted from the specimen – 9.9 kW
- heat flux on external surface of specimen opposite acoustic mirror – 0.97 MW/m$^2$
- maximum heat flux at the surfaces of water channels – 7.4 MW/m$^2$
- DNB margin > 1.6




**N.b.!**
Uneven temperature field explained by the peculiarities of the cooling system provokes faster ablation right across the acoustic mirror

# Pr1-MCP-8 results

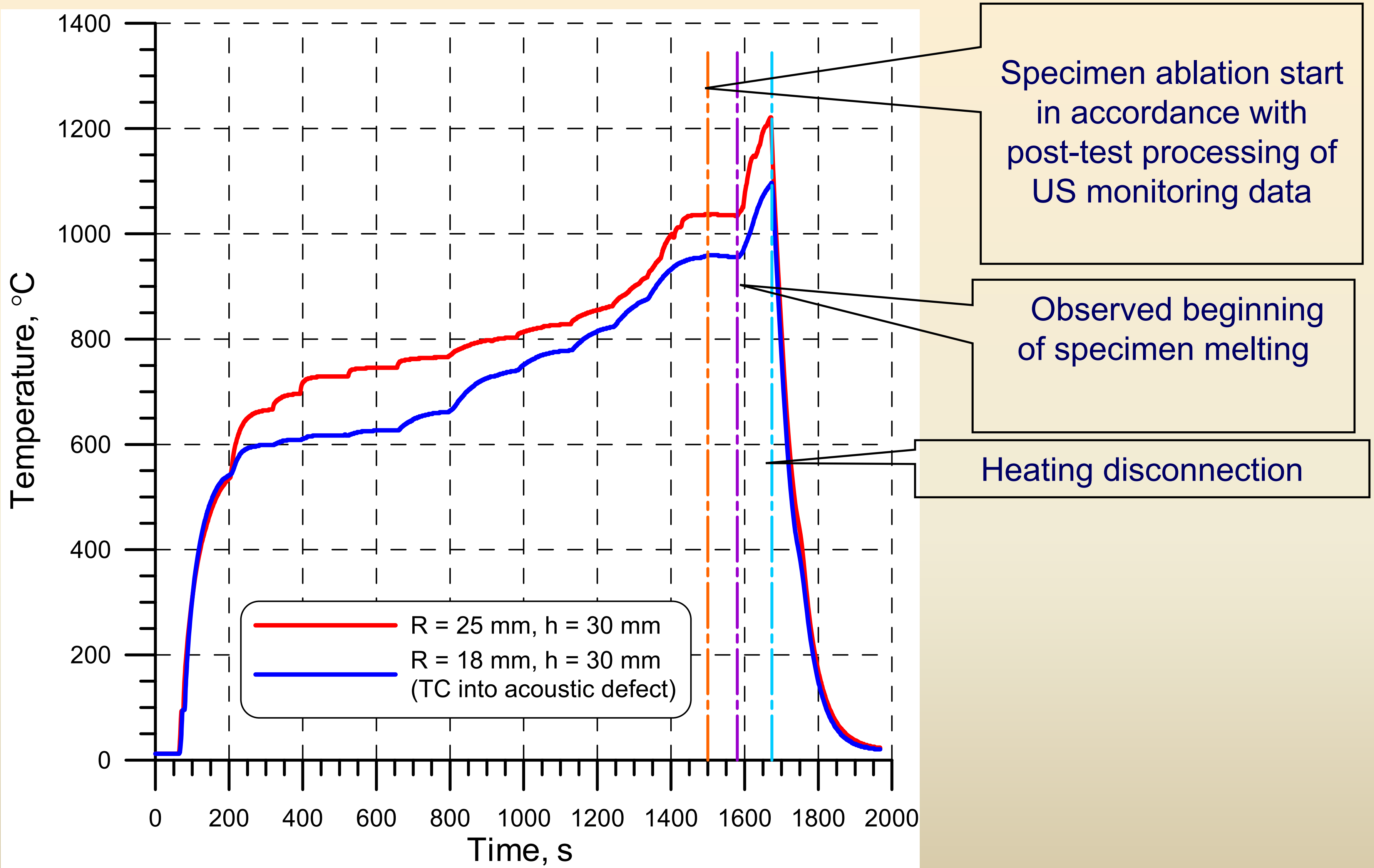
## Power extracted from the specimen



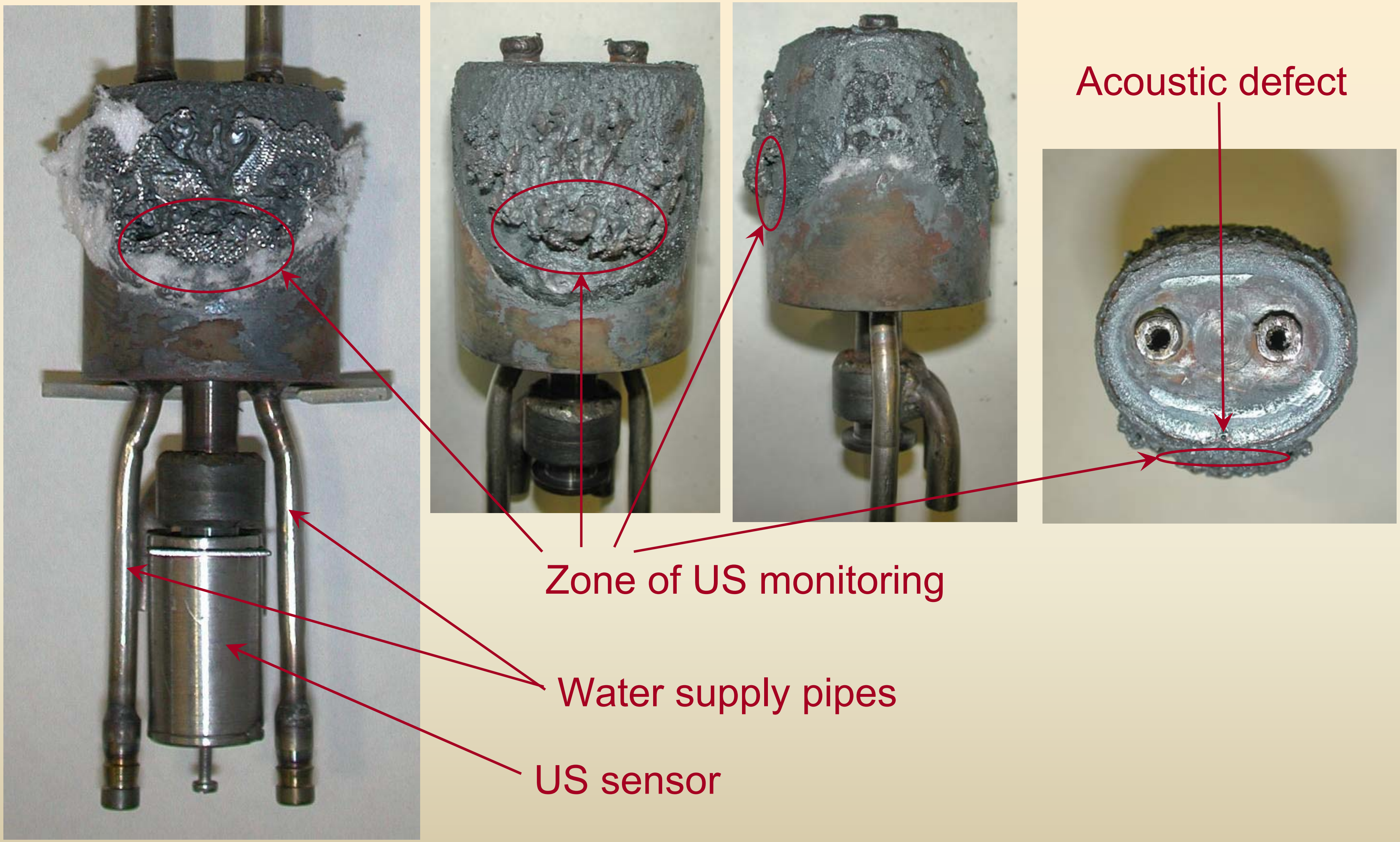

- Maximum power into the specimen: **12.2 kW**
- Average heat flux: **1.20 MW/m²**
- **No DNB indications**

# Pr1-MCP-8 results (2)

## TC readings

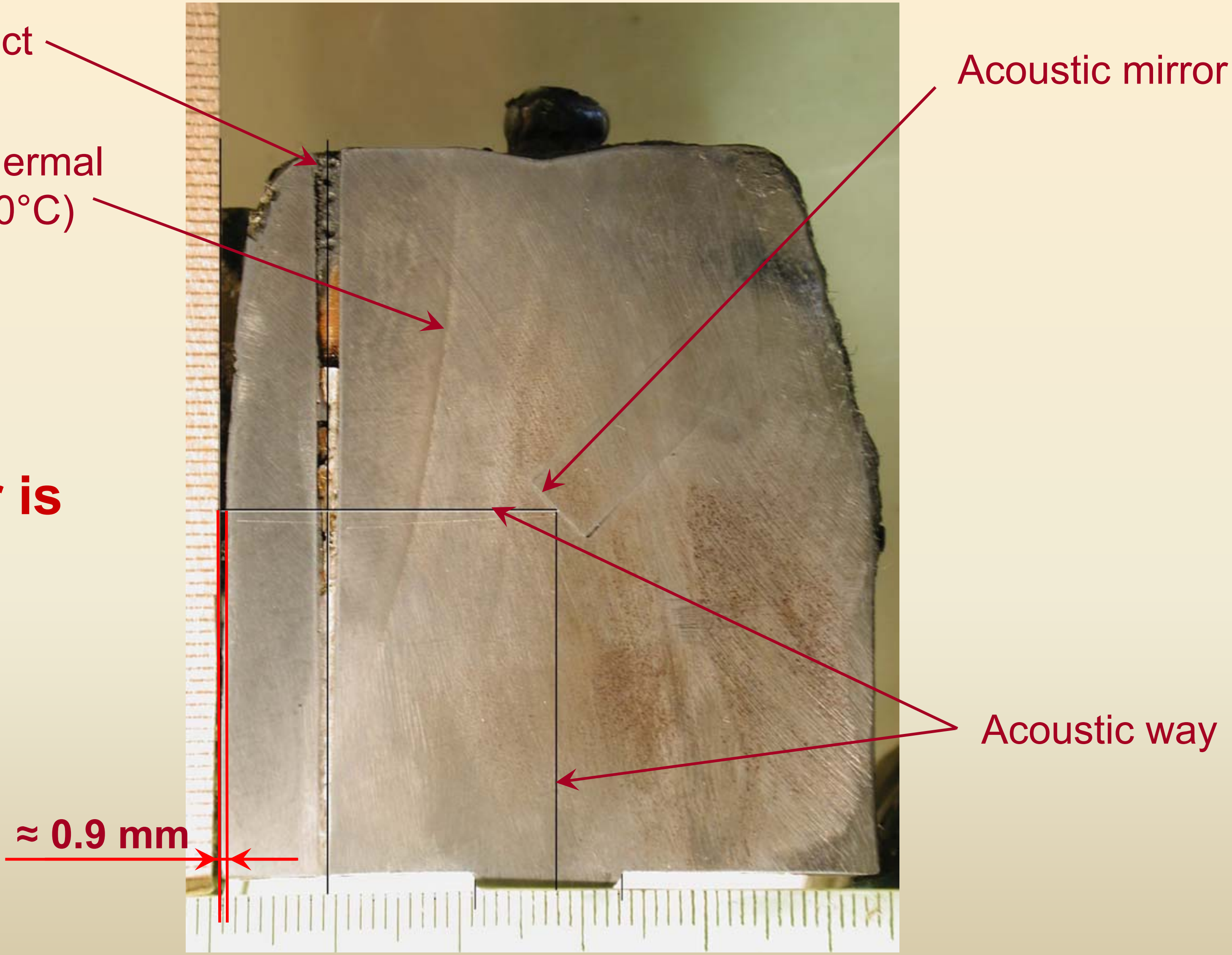


# Pr1-MCP-8 results (3)
## Specimen view after the pretest



# Pr1-MCP-8 results (4)

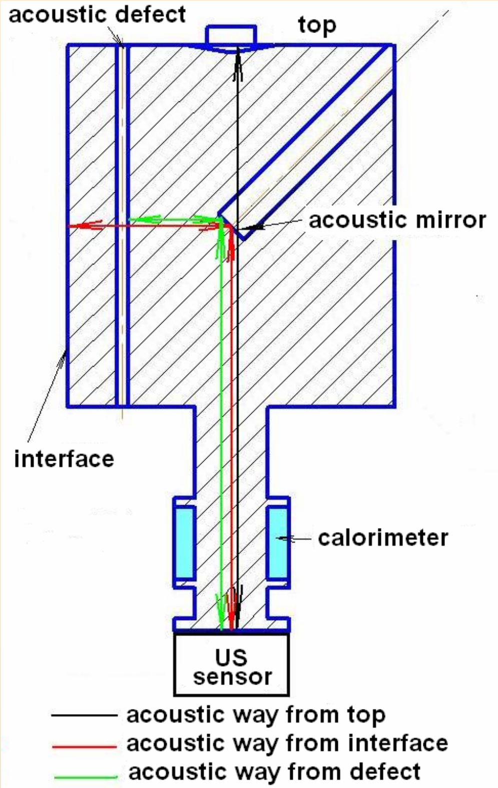
## View of specimen axial section

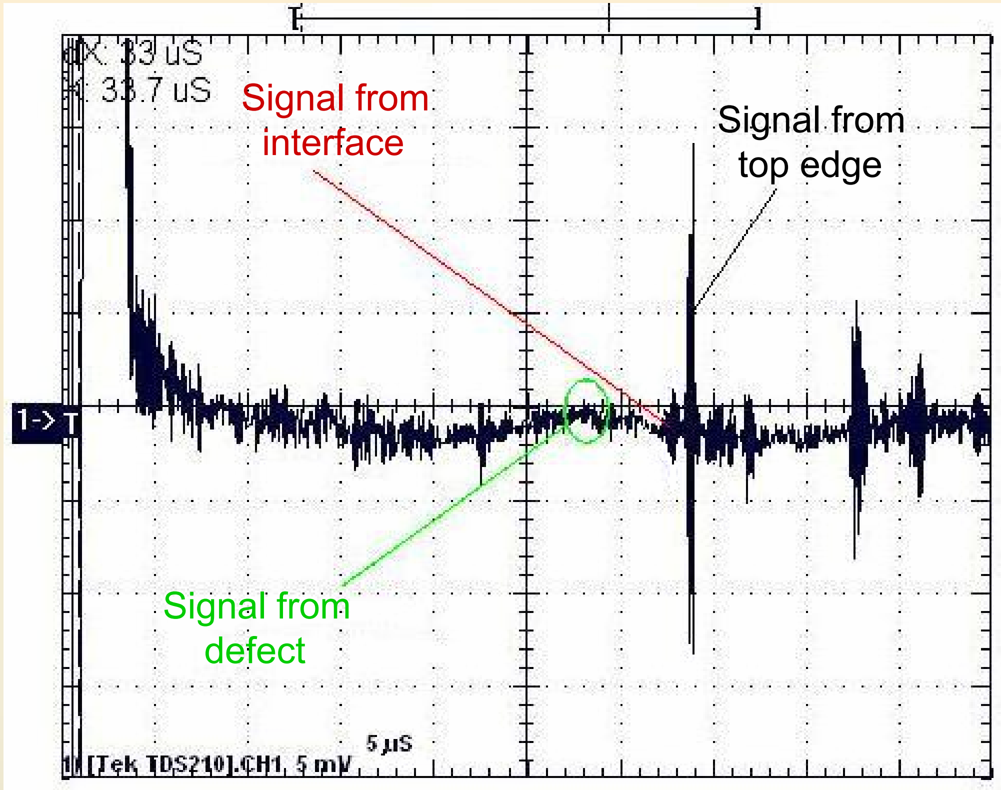



**Molten layer is removed!**

# Pr1-MCP-8 results (5)

## US monitoring of ablation



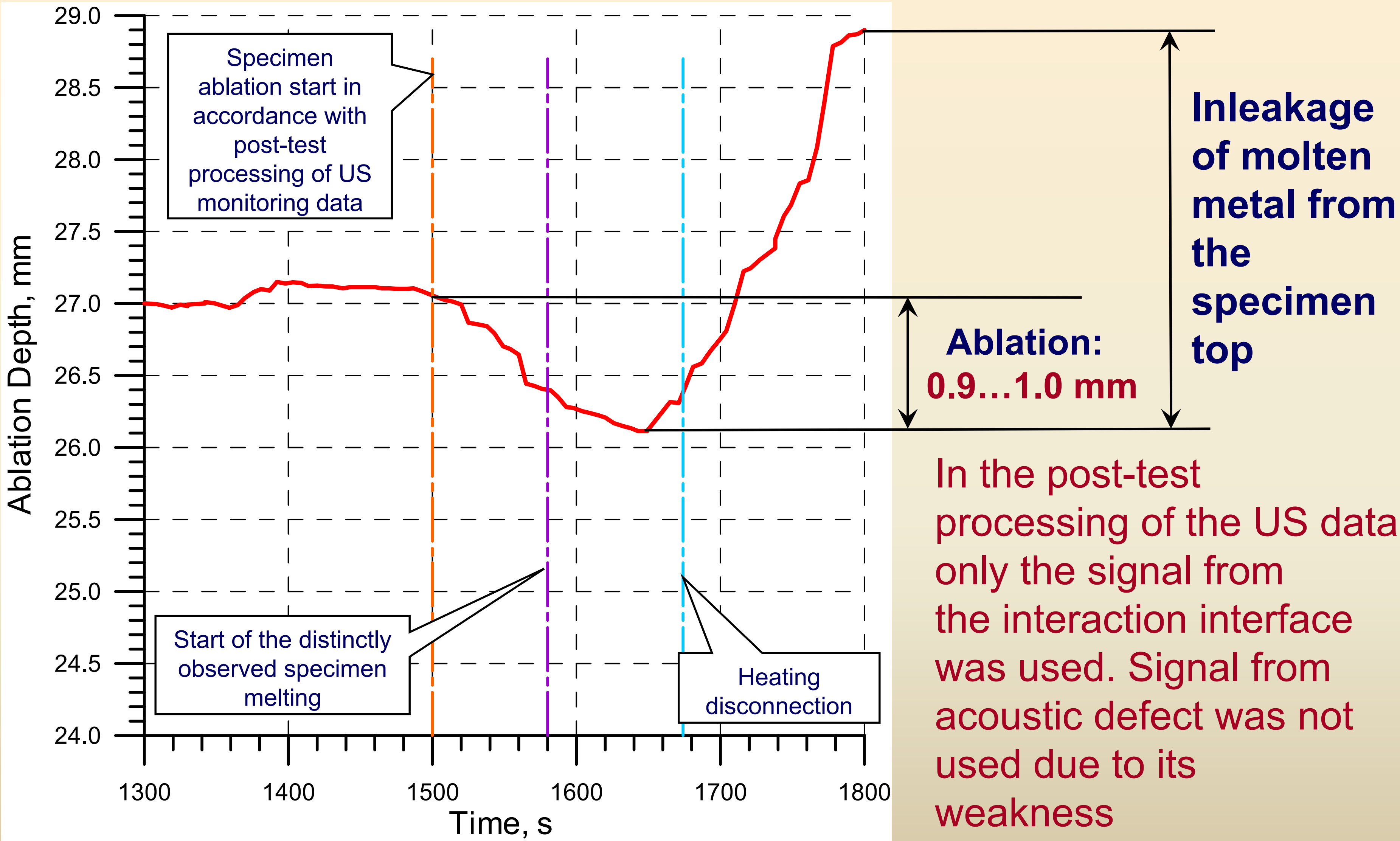




- Wanted signal reflected from the interface surface is several times weaker than the signal reflected from the specimen top edge
- Signal from the defect is barely detectable above the level of noise

**Explanation:** double sound transfer through the small acoustic mirror

# Pr1-MCP-8 results (6)

## Ablation depth




In the post-test processing of the US data only the signal from the interaction interface was used. Signal from acoustic defect was not used due to its weakness

# Pr1-MCP-8 results (7)

- DNB margin and efficiency of specimen cooling are experimentally confirmed
- Maximum corrosion in the experiment is expected in the US monitoring zone
- The US monitoring system efficiency is demonstrated, though its sensitivity is lower than for specimens with horizontal orientation of the interface

# Conclusions

- Designs for steel specimens with a vertical interface orientation is developed
- The efficiency of cooling system and US monitoring is experimentally proven
- Preparation of MCP-8 has been completed. The test will be conducted soon

# Planning

- According to the Experimental Matrix of the Project, 1 more test is to be performed
- Due to a delay in Project implementation a 6-month project time extension without additional funding has been approved by the ISTC

# METCOR-P project reporting

| Report code | Title | Status |
|---|---|---|
| RMP- 01 | Interaction of molten corium with vertically positioned vessel steel specimen in the neutral atmosphere. Test MCP-1 | Done |
| RMP- 02 | Interaction of molten corium $UO_{2+x}$-$ZrO_2$ with horizontally positioned vessel steel specimen in the steam atmosphere. Test MCP-2 | |
| RMP- 03 | Interaction of suboxidized corium melt with steel at the replacement of neutral atmosphere by oxidizing atmosphere. Test MCP-3 | |
| F1-3592/2008 | Annual report on METCOR-P. First year | |
| F2-3592/2009 | Annual report on METCOR-P. Second year | |
| RMP- 04 | Interaction of molten corium with European vessel steel in oxidizing atmosphere. Test MCP-4 | |
| RMP-05r | Interaction of suboxidized molten corium with European vessel steel. Test MCP-5 | Ready in Russian version |
| | Oxidation of the uranium-containing metallic melt in steam. Test MCP-6 | In progress |
| | Oxidation of the suboxidized molten corium in steam. Test MCP-7 | |

✓First three reports have been sent to ITU under export control conditions

# Publications during METCOR-P


1. Bechta S.V., Granovsky V.S., Khabensky V.B., Krushinov E.V., Vitol S.A., Sulatsky A.A., Gusarov V.V., Almjashev V.I., Lopukh D.B., Bottomley D., Fischer M., Piluso P., Miassoedov A., Tromm W., Altstadt E., Fichot F., Kymalainen O. Interaction between Molten Corium $UO_{2+x}$-$ZrO_2$-$FeO_y$ and VVER Vessel Steel // Proceeding of ICAPP'08, Anaheim, CA USA, June 8-12, 2008, Paper 8052.
2. Bechta S.V., Granovsky V.S., Khabensky V.B., Krushinov E.V., Vitol S.A., Sulatsky A.A., Gusarov V.V., Almjashev V.I., Mezentseva L.P., Krushinov E.V., Kotova S.Yu., Kosarevsky R.A., Barrachin M., Bottomley D., Fischer M., Fichot F. Corium Phase Equilibria from MASCA, METCOR and CORPHAD Results // Nucl. Eng. and Design, 238, p. 2761-2771 (2008).
3. Bechta S.V., Granovsky V.S., Khabensky V.B., Krushinov E.V., Vitol S.A., Sulatsky A.A., Gusarov V.V., Almjashev V.I., Lopukh D.B., Bottomley D., Fischer M., Piluso P., Miassoedov A., Tromm W., Altstadt E., Fichot F., Kymalainen O. VVER Vessel Steel Corrosion at Interaction with Molten Corium in Oxidizing Atmosphere // Nucl. Eng. and Design, 239 (2009), p. 1103-1112.

# Publications during METCOR-P (2)

4. Bechta S.V., Granovsky V.S., Khabensky V.B. et.al. VVER Steel Corrosion during In-Vessel Retention of Corium Melt // Proceeding of the 3rd European Review Meeting on Severe Accident Research (ERMSAR 2008), Paper 2.7, Nesseber, Bulgaria, September 23-25 (2008).
5. Bechta S.V., Granovsky V.S., Khabensky V.B. et.al. Interaction between Molten Corium $UO_{2+x}$-$ZrO_2$-$FeO_y$ and VVER Vessel Steel // J. Nucl. Technology, Vol. 170, №1 (2010), p. 210-218.
6. Bechta S.V., Granovsky V.S., Khabensky V.B. et.al. The influence of thermogradient conditions on physicochemical interaction of the suboxidized molten corium with steel during in-vessel retention of the melt. (Russian version).