A.P. Alexandrov Research Institute of Technology

I S T C

М Н Т Ц

INVECOR pretest calculations of molten pool and lower head model

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Objectives

- ✓ Determine characteristics of molten pool, temperature and stress-and-strain conditions of the lower head model
- ✓ Optimize conditions of melt heating and develop recommendations on the location of electrodes and model geometry

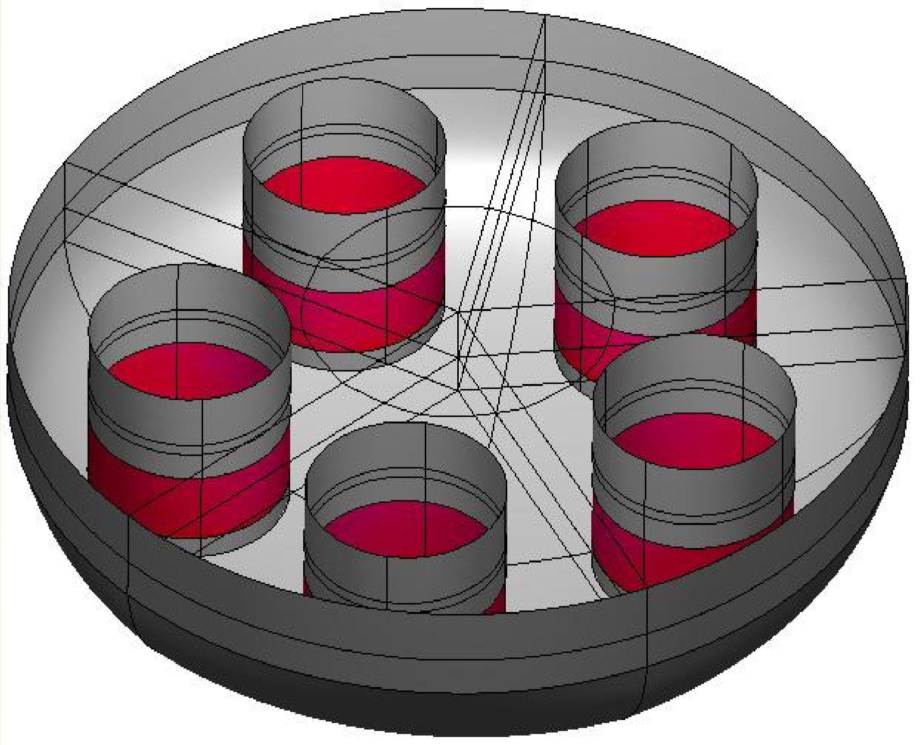
Methodology

- ✓ **Multi-optional calculations of molten pool thermal hydrodynamics at different model geometries and electrode positioning using the DYMELT program:**
- **Integral approach was used for solving problems of melt hydrodynamics taking into account melting/crystallization and thermal conductivity of the solid wall**
- **3-D formulation (1/10 of the lower head model – sector 36°)**
- **Quasi-stationary Laminar regime of convection (Navier-Stoks system of equations, energy and continuity)**
- **Calculations of the model thermal conditions using the ANSYS package**

Basic model of the vessel

Characteristics of the model

- Semi-elliptical lower head
- Inner diameter – 400 mm
- Wall thickness – 90 mm
- Number of heaters – 5
- Minimum distance from the heater bottom to the internal surface of the model– 10 mm
- Distance from the heater axis to the model axis – 120 mm
- Heater diameter – 90 mm
- Height of the heater active zone – 45 mm
- Height of the heater passive zone – 10 mm
- Distance from the top point of the heater active zone to corium surface 5 mm
- Distance from corium surface to thermal screen 25 mm
- Power capacity of a single heater 18 kW, total power – 90 kW
- Corium mass – 64 kg



Basic model of the vessel(2)

Boundary conditions

- External water-cooled surface of the lower head model – 100°C
- Heat flux from corium top surface by radiation through transparent gas to screen and lateral surface of the model
- Ideal screen - zero heat flux from its outside surface
- Heating part of electrodes is assumed to have a uniform heat flux distribution
- Not heating part of electrodes has thermal insulation
- There is no upward heat sink along electrodes

Basic model of the vessel(3)

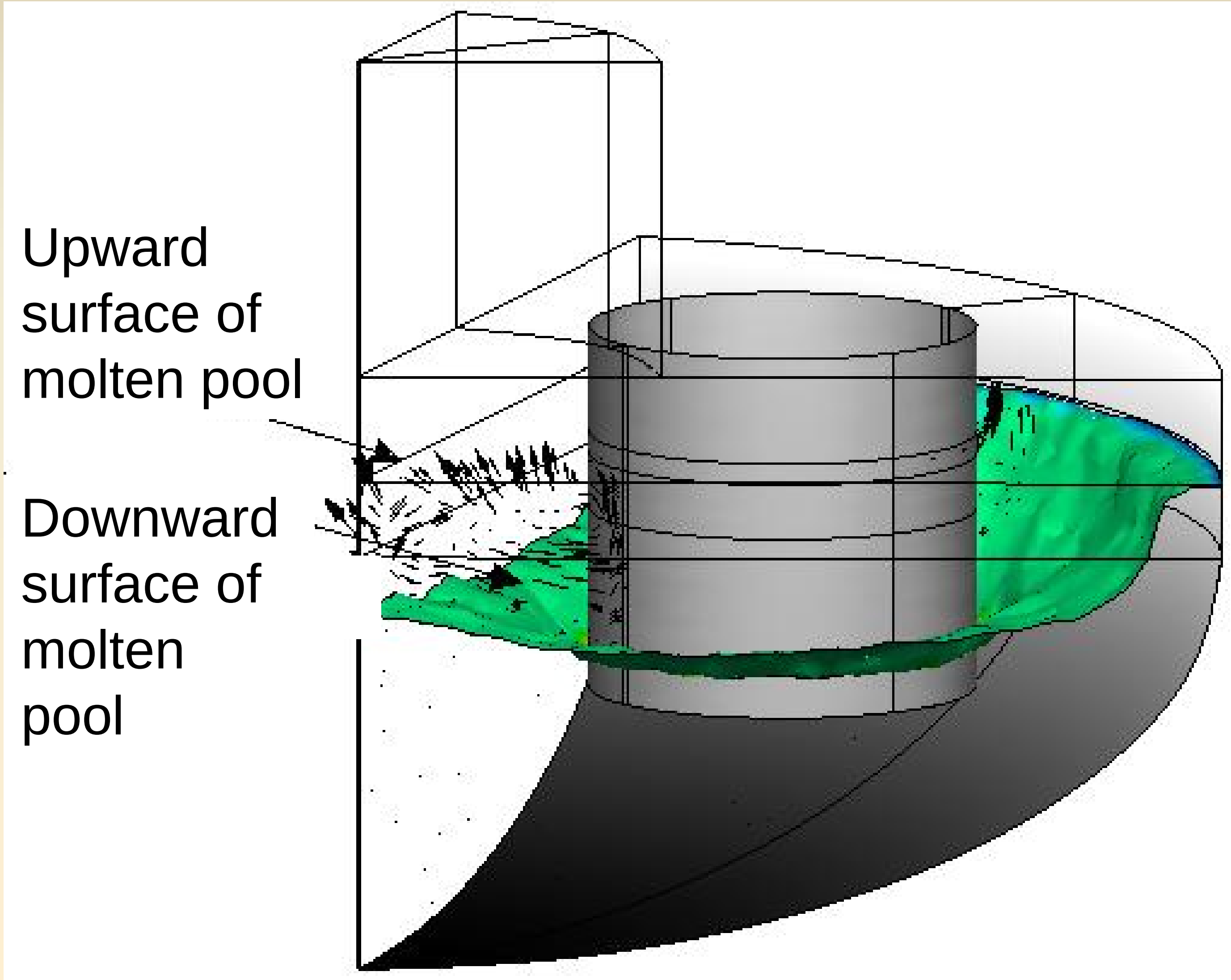
Thermophysical parameters

- **Solidus temperature 2150°C (corium C-30)**
- **Corium liquidus temperature 2300°C**
- **Thermal conductivity of solid and liquid corium 3.3 W/m·K**
- **Thermal conductivity of steel 30 W/m·K**
- **Thermal conductivity of corium and steel does not depend on temperature**
- **Emissivity of corium, inside surface of the model and screen – 0.8**

Basic model of the vessel(4)

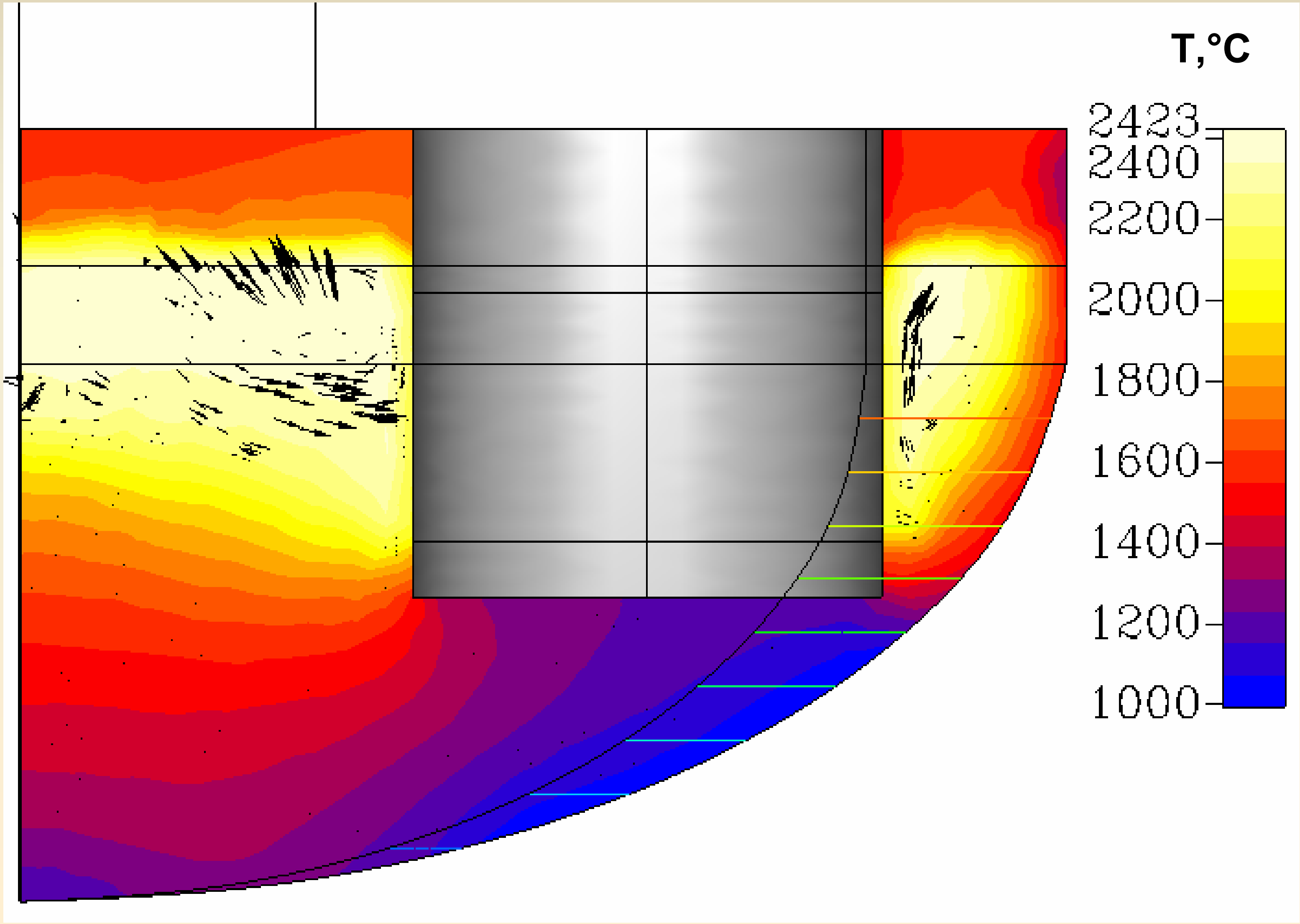
Calculation results

Molten pool configuration



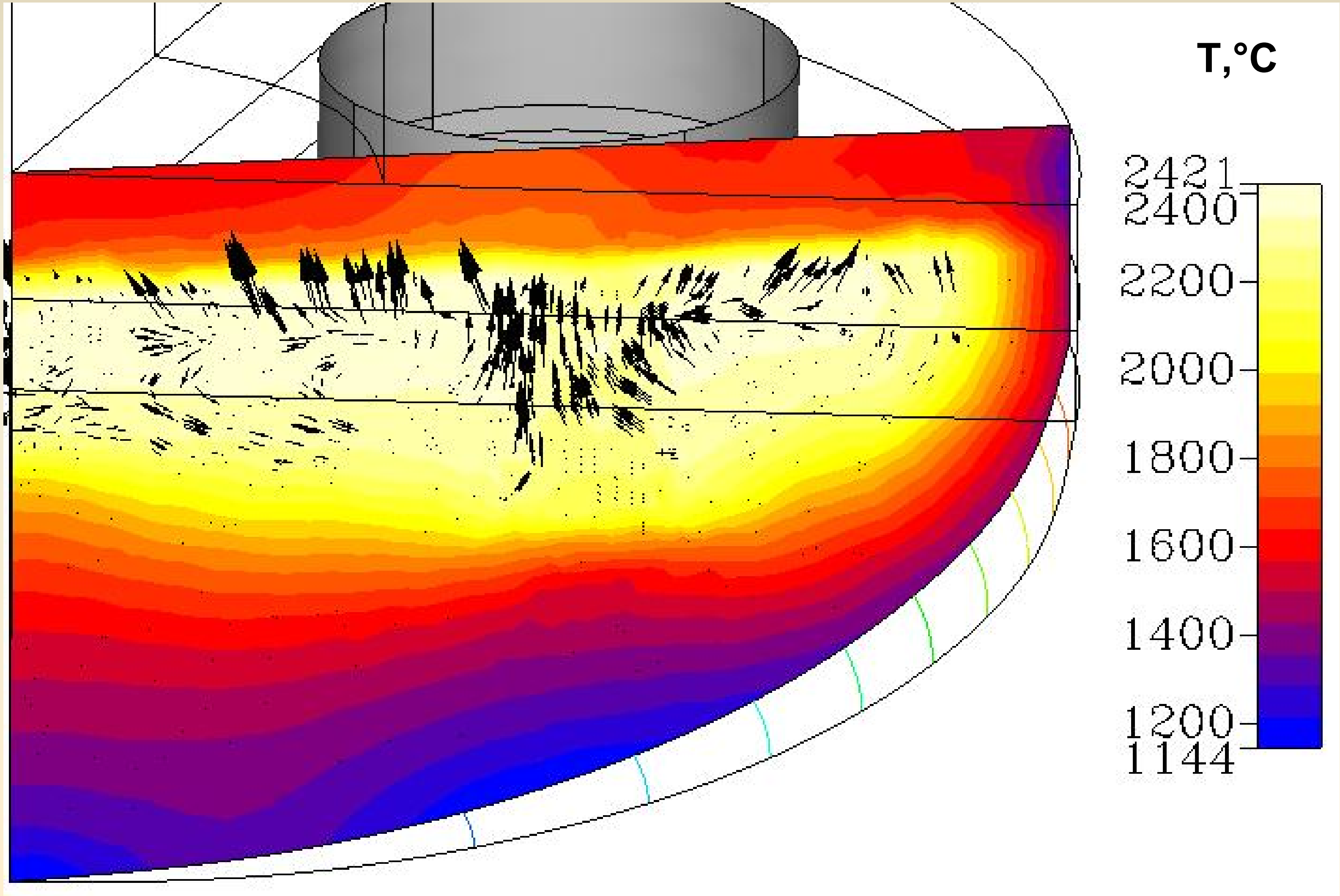
Basic model of the vessel (5)

Corium temperature field in the axial section of the heater



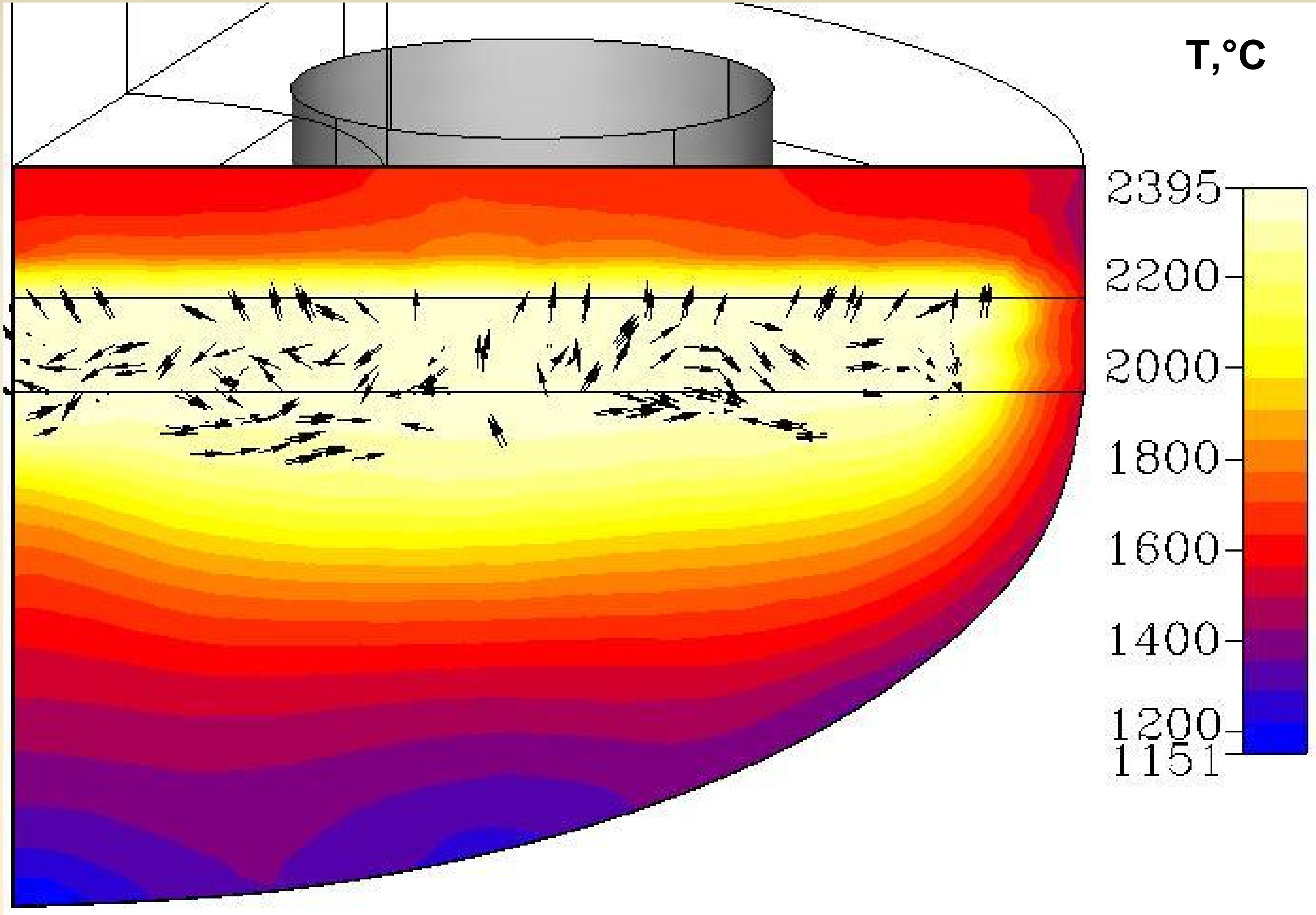
Basic model of the vessel (6)

Corium temperature field in the section rotated by 18°



Basic model of the vessel (7)

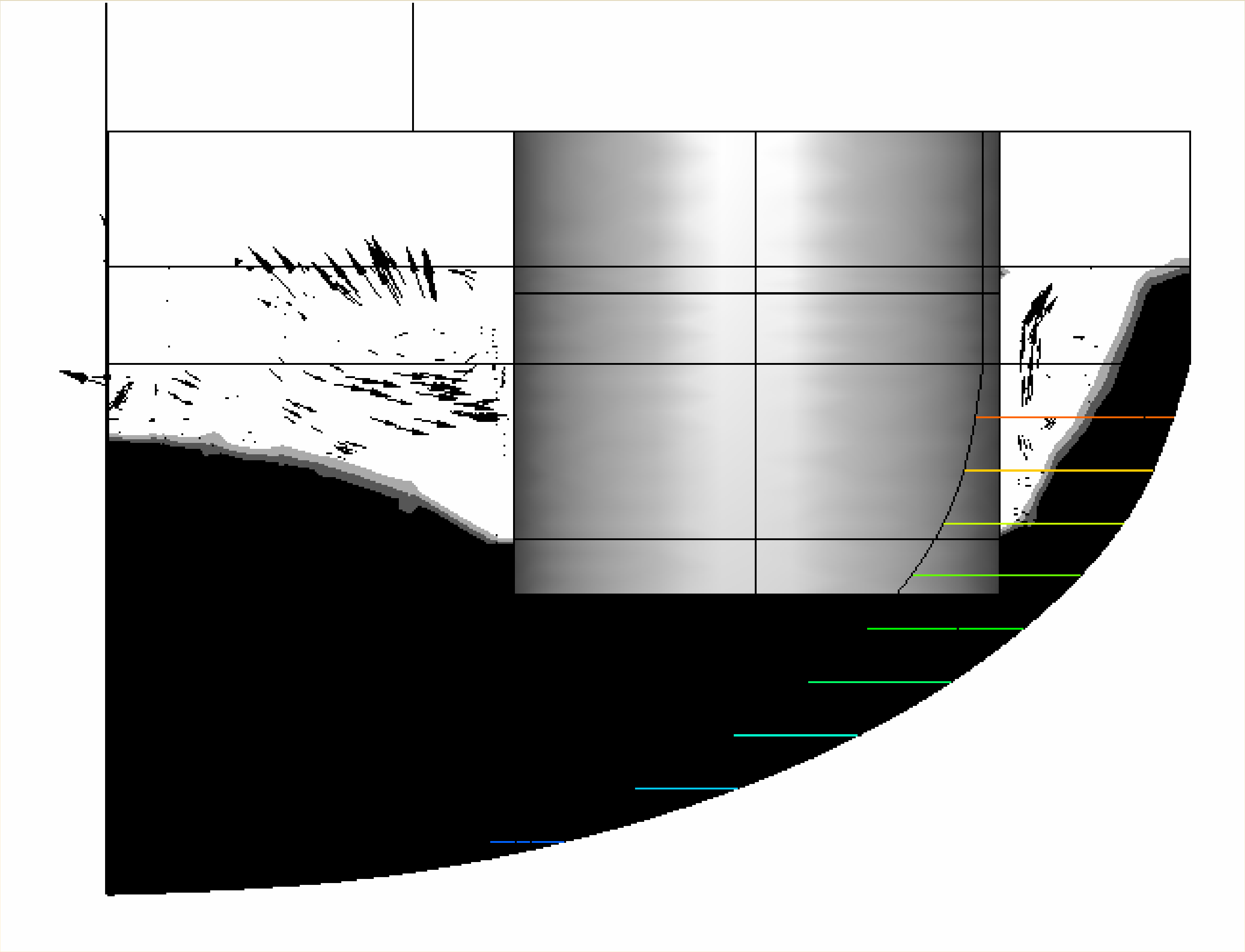
Corium temperature field in the inter- heater cross-section



Basic model of the vessel(8)

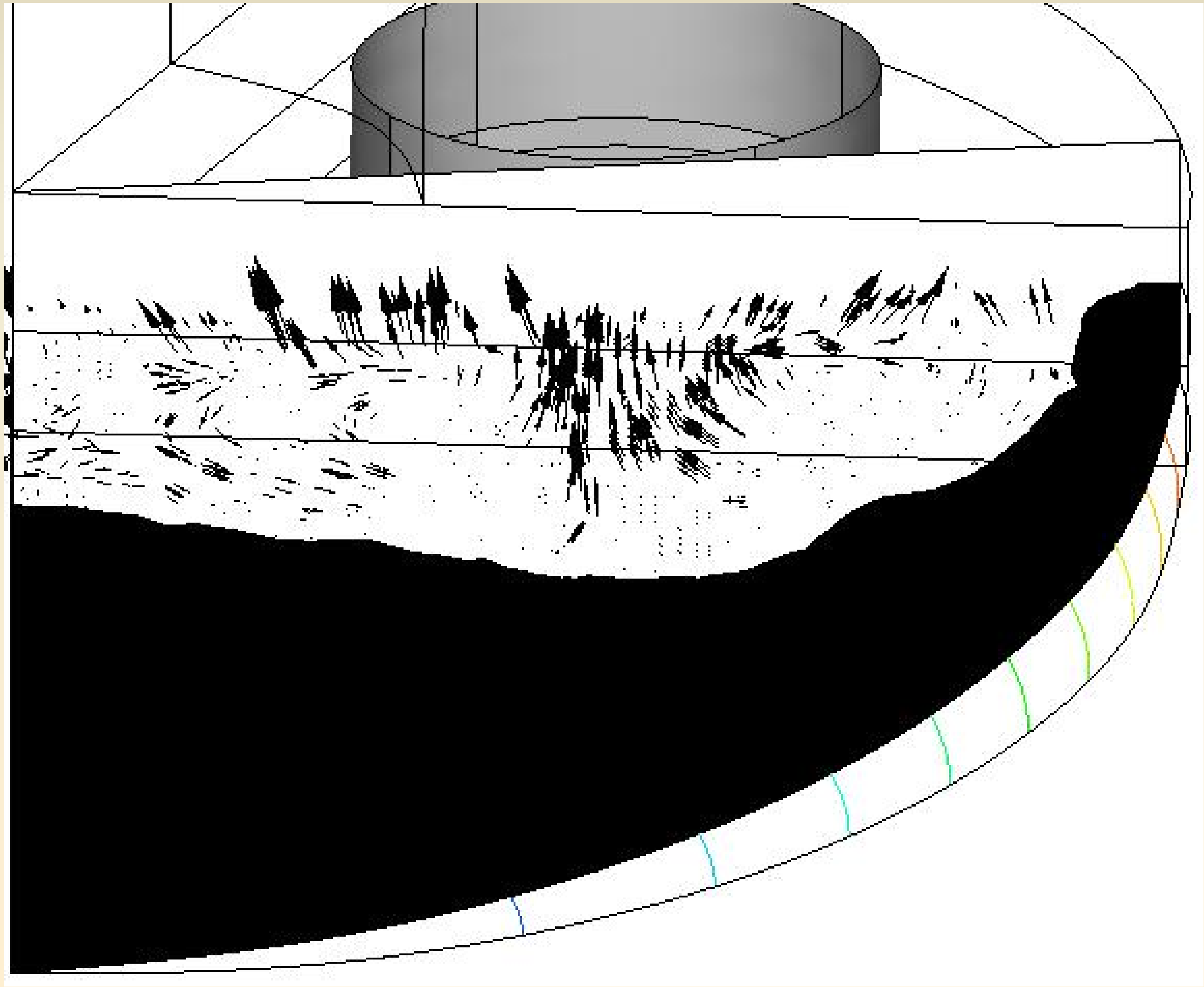
Calculation results

Crust thickness in the axial section of the heater



Basic model of the vessel(9)

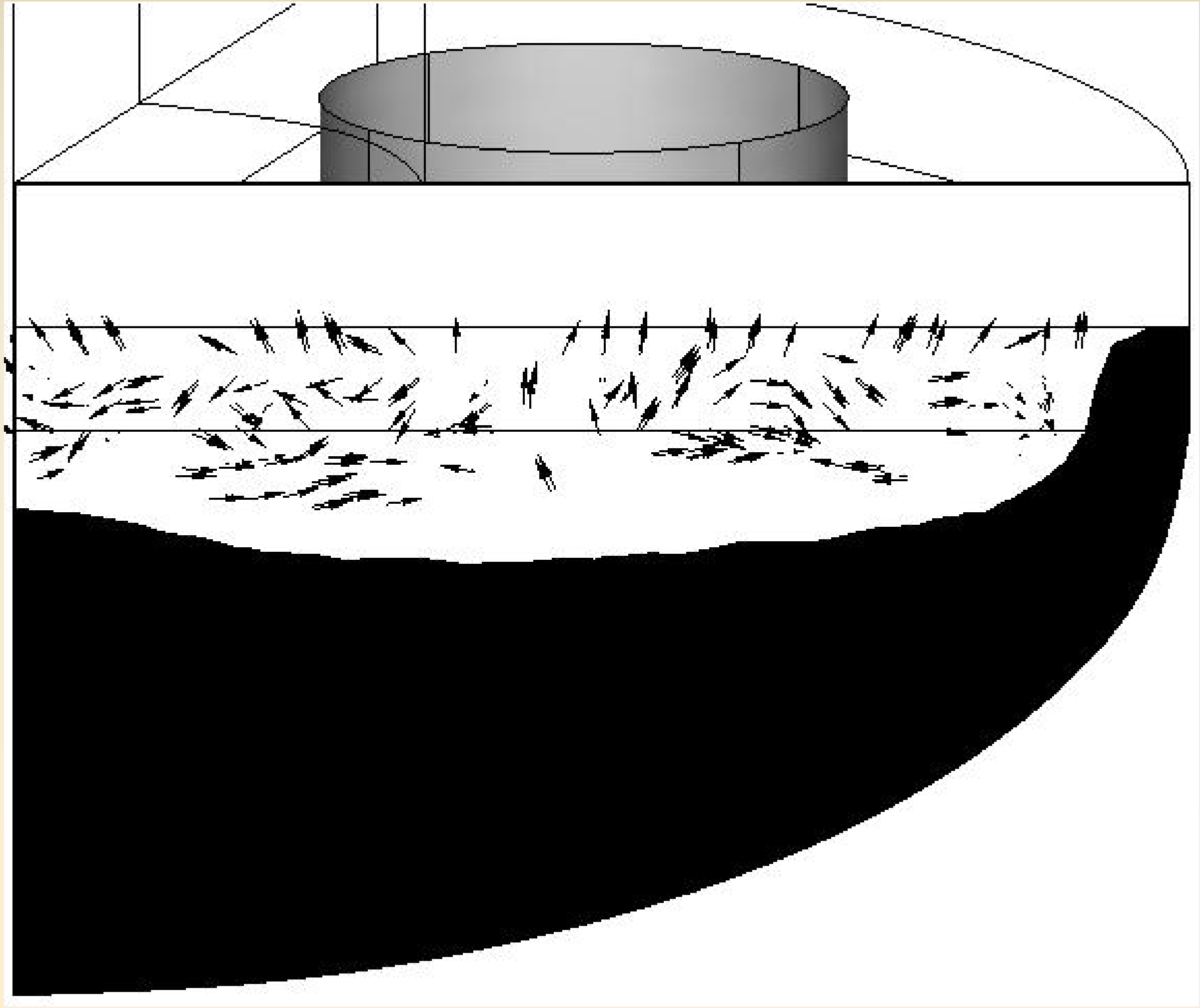
Calculation results **Crust thickness in the section rotated by 18°**



Basic model of the vessel(10)

Calculation results

Crust thickness in the inter-heater section



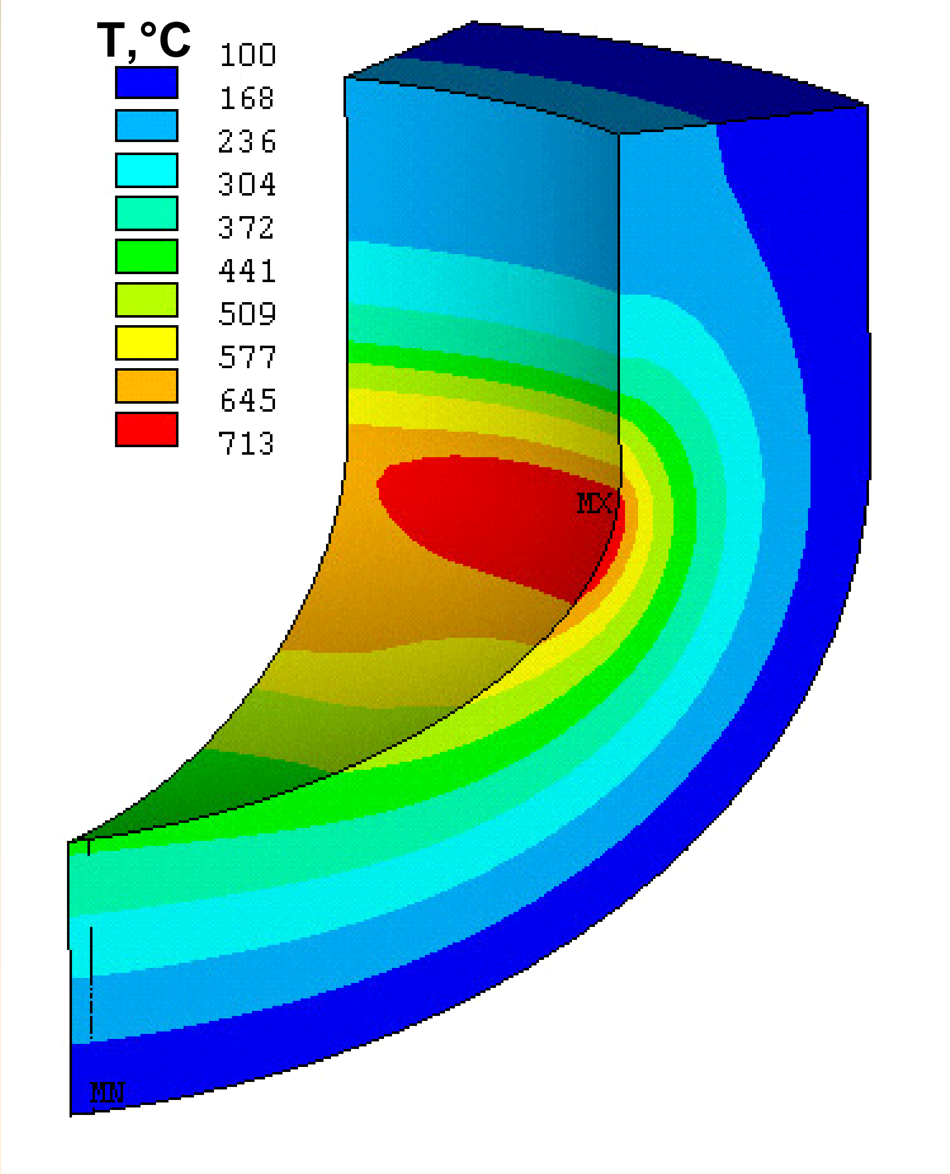
Basic model of the vessel(11)

Calculation results

Temperature field in the lower head model

Max temperature does not exceed ≈700°C

External insulation of the lower head model is necessary



Basic model of the vessel (12)

Calculation with external thermal insulation

• The wall temperature condition was calculated by using ANSYS

•Boundary condition:

- heat flux distribution on the internal wall produced by molten pool modeling
- 100 C at water cooled external wall

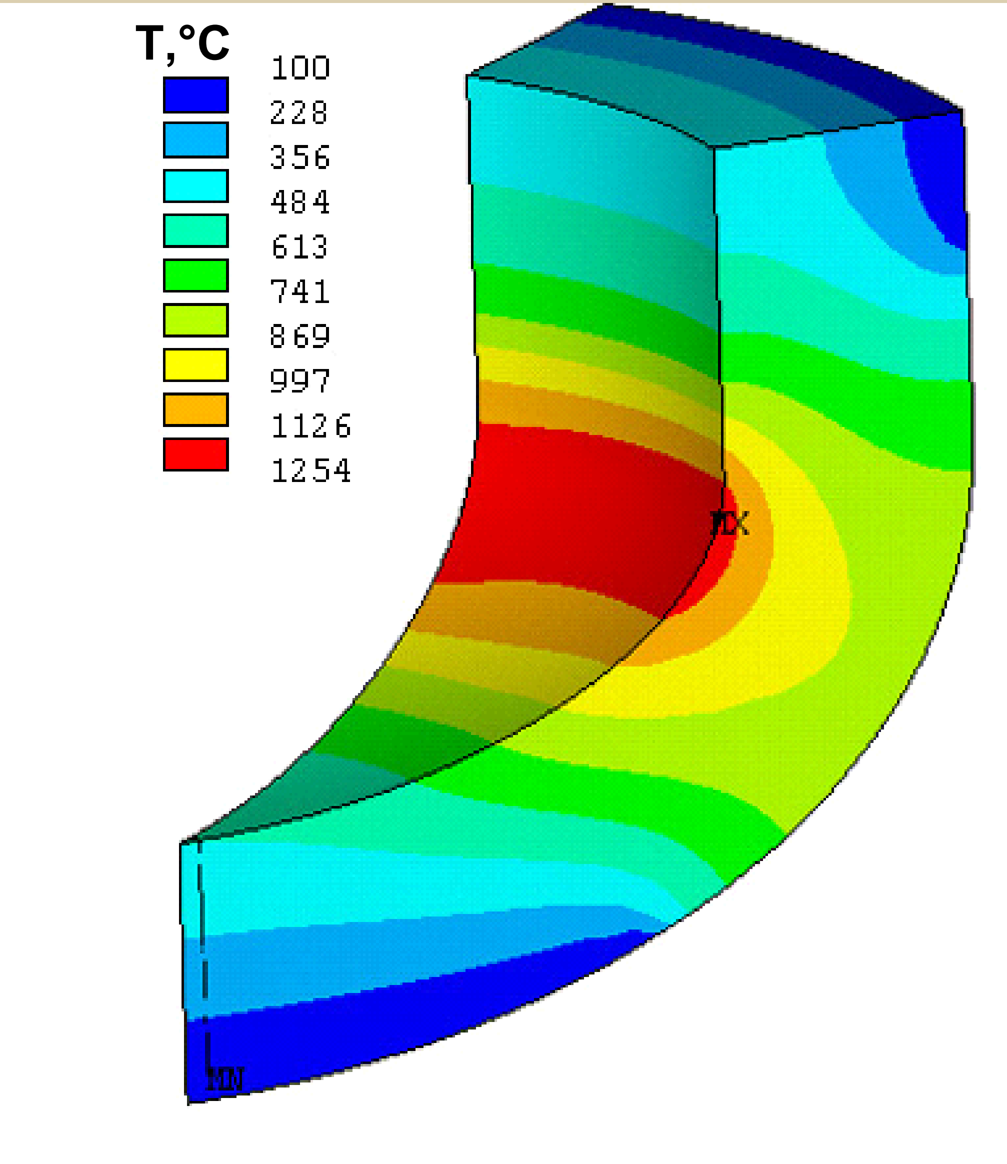
Thermal insulation of axi-symmetrical belt on the external surface of the lower head model and of the surface above the screen

• Thermal insulation is ideal

Basic model of the vessel (13)

Calculation results

Temperature field in the lower head model with partial thermal insulation

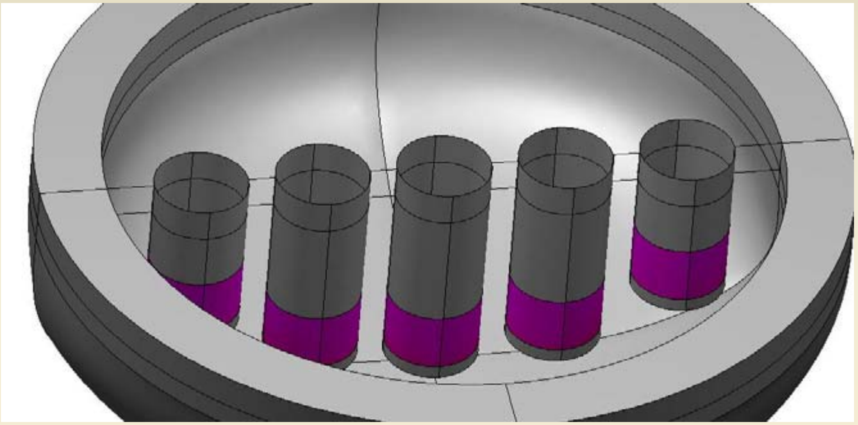


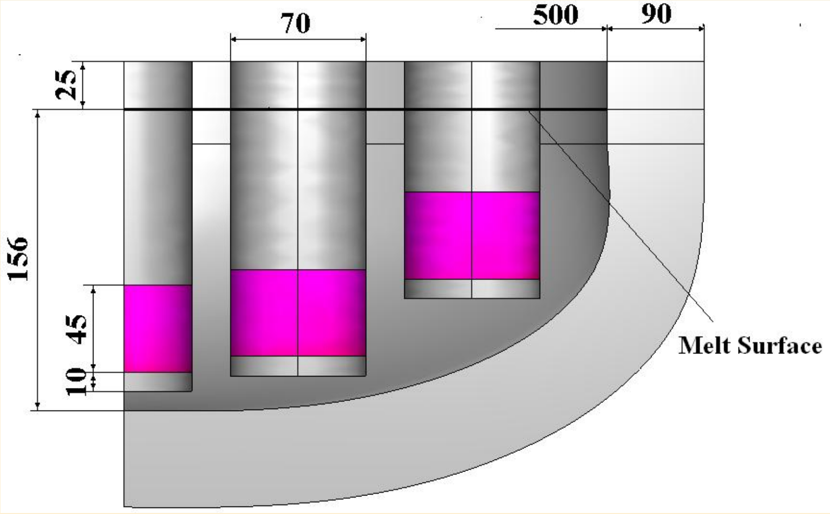
Maximum temperature about 1200°C

Basic model of the vessel (14)

Calculation with electrodes positioned in one plane (quasi-slice geometry)

- ✓ In order to get realistic temperatures and heat fluxes on the internal vessel surface, at least near the axial plane of the model, a version with all electrodes positioned in the plane was considered
- ✓ For that model diameter was increased to 500 mm, and the mass of corium charge to 150 kg. Note: for this a part of solid charge can be placed on the model periphery, the rest of mass can be pored from the furnace
- ✓ Other characteristics of the model and boundary conditions are close to the basic version

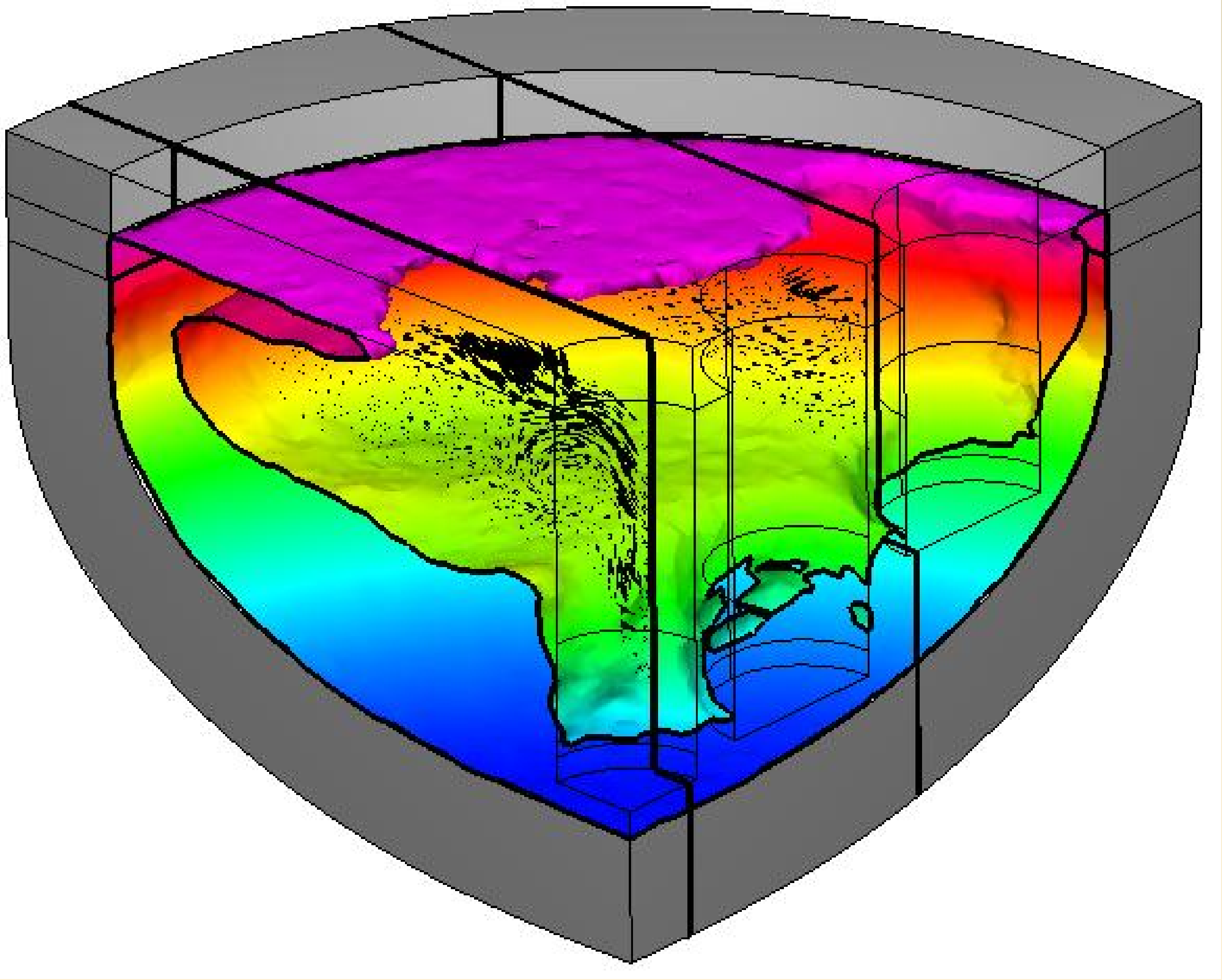




Basic model of the vessel (15)

Calculation results

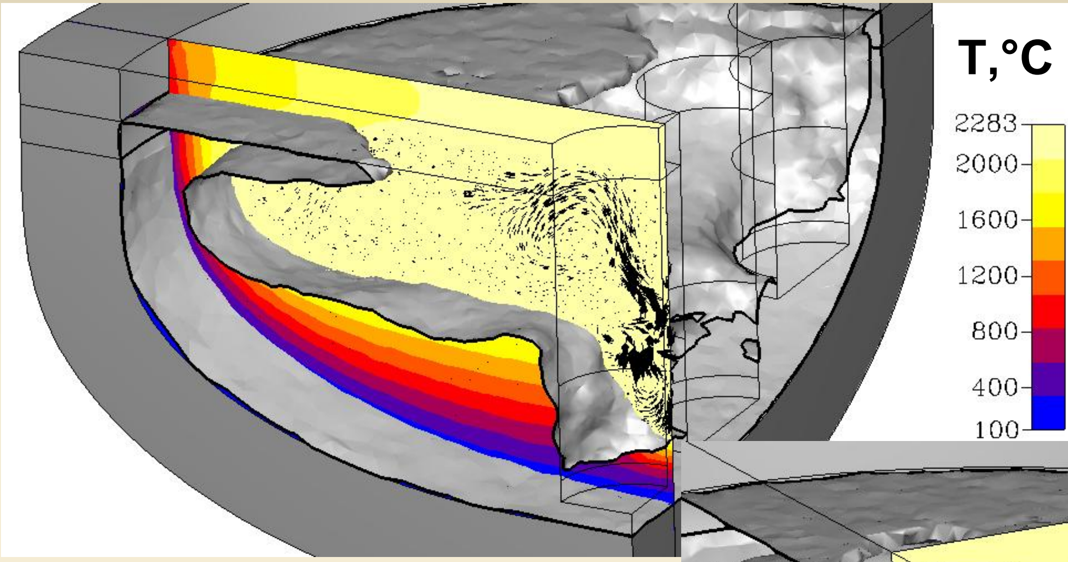
Molten pool configuration

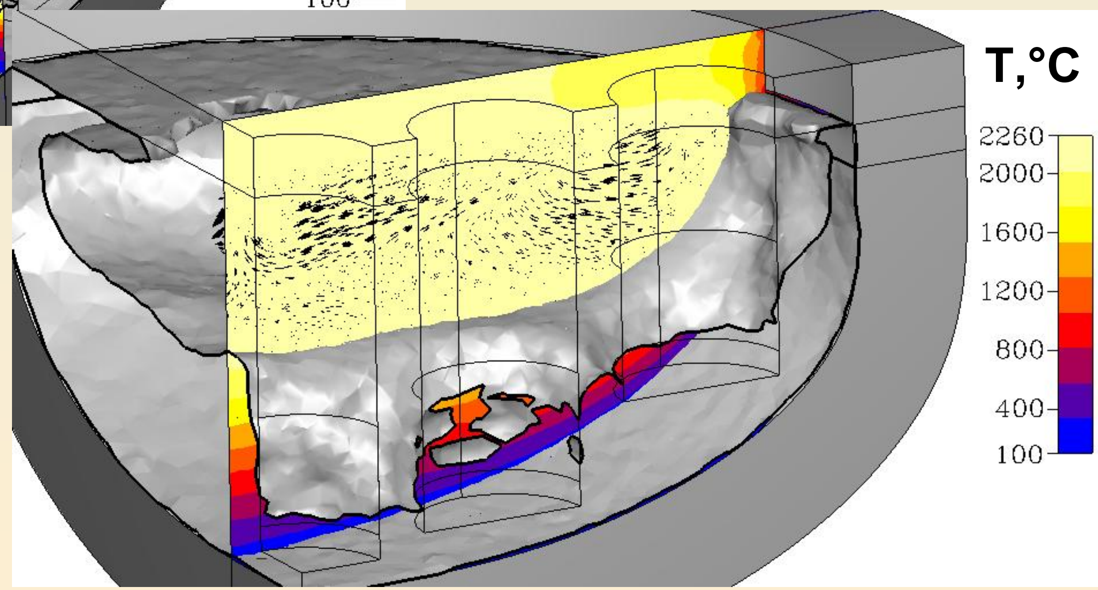


✓**Substantial improvement has not been achieved**

Basic model of the vessel(16)

Temperature distribution in vertical sections





Basic model of the vessel (17)

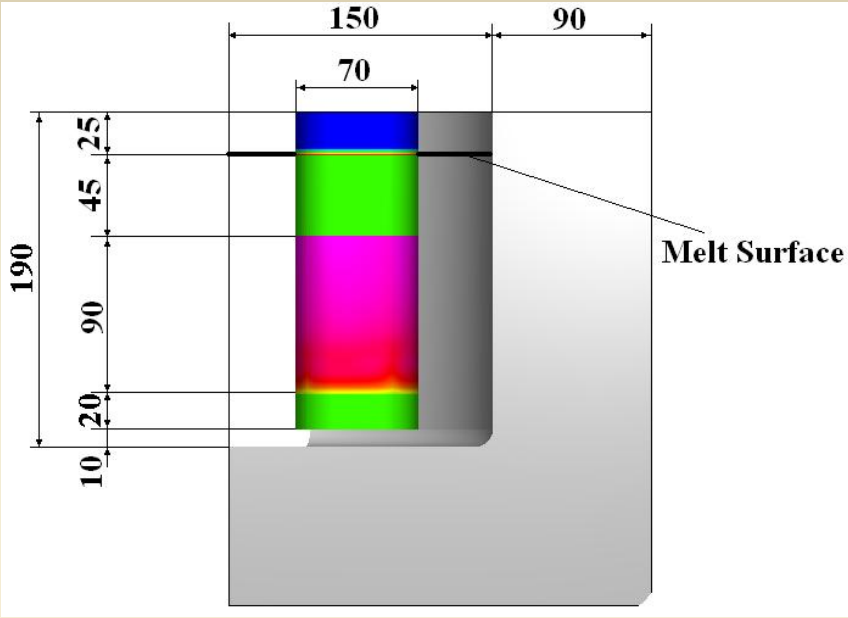
Main results of the basic model calculations

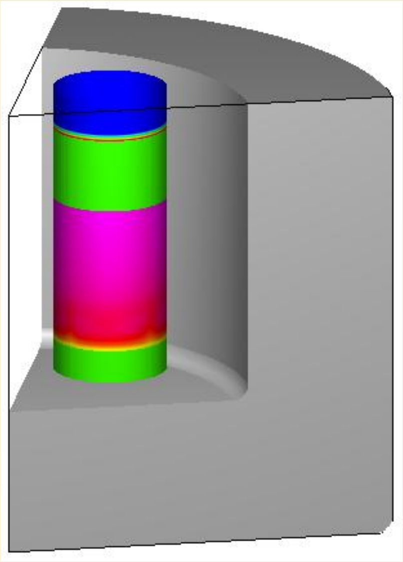
- Bottom part of the basic model cannot be efficiently heated
- Molten pool is small, considerable part of solid corium lies under it. Elliptical part of the lower head “does not work”
- In absence of external insulation temperature on the internal surface of the model does not exceed ≈700°C
- A considerable thickness of the model wall and consequent heat fluxes along the wall require the insulation of a large surface. At this maximum temperature on the internal surface of the model is approx. 1200°C
- If the wall thickness is reduced, smaller surface can be insulated, but in this case the pool is much smaller

Cylindrical model

Model characteristics

- Internal diameter of the model – 300 mm
- Wall thickness – 90 mm
- Number of heaters – 5
- Minimum distance from the heater bottom to the model internal surface– 10 mm
- Distance from the heater axis to the model axis – 75 mm
- Heater diameter – 70 mm
- Height of the heater active part
  – 90 mm
- Height of the heater lower (passive) part – 20 mm
- Distance from the top point of the active part to corium surface 45 mm
- Distance from the corium surface to screen – 25 mm
- Power of a single heater 18kW,
  Total power – 90 kW
- Corium mass – 64 kg





Cylindrical model(2)

Calculation methodology, boundary conditions and thermophysical parameters are the same as in the basic model (calculations without partial insulation)

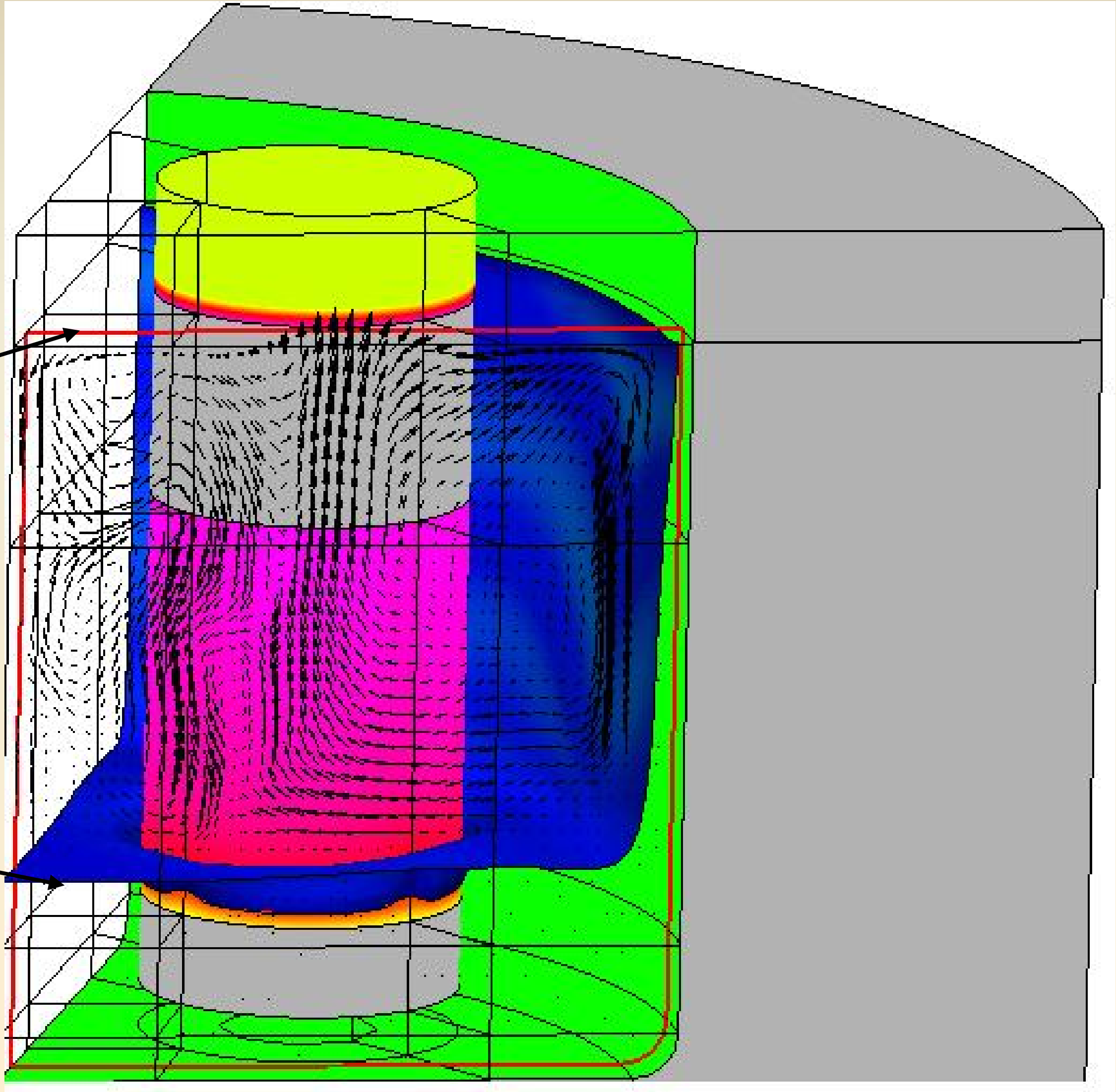
Cylindrical model(3)

Calculation results

Molten pool configuration

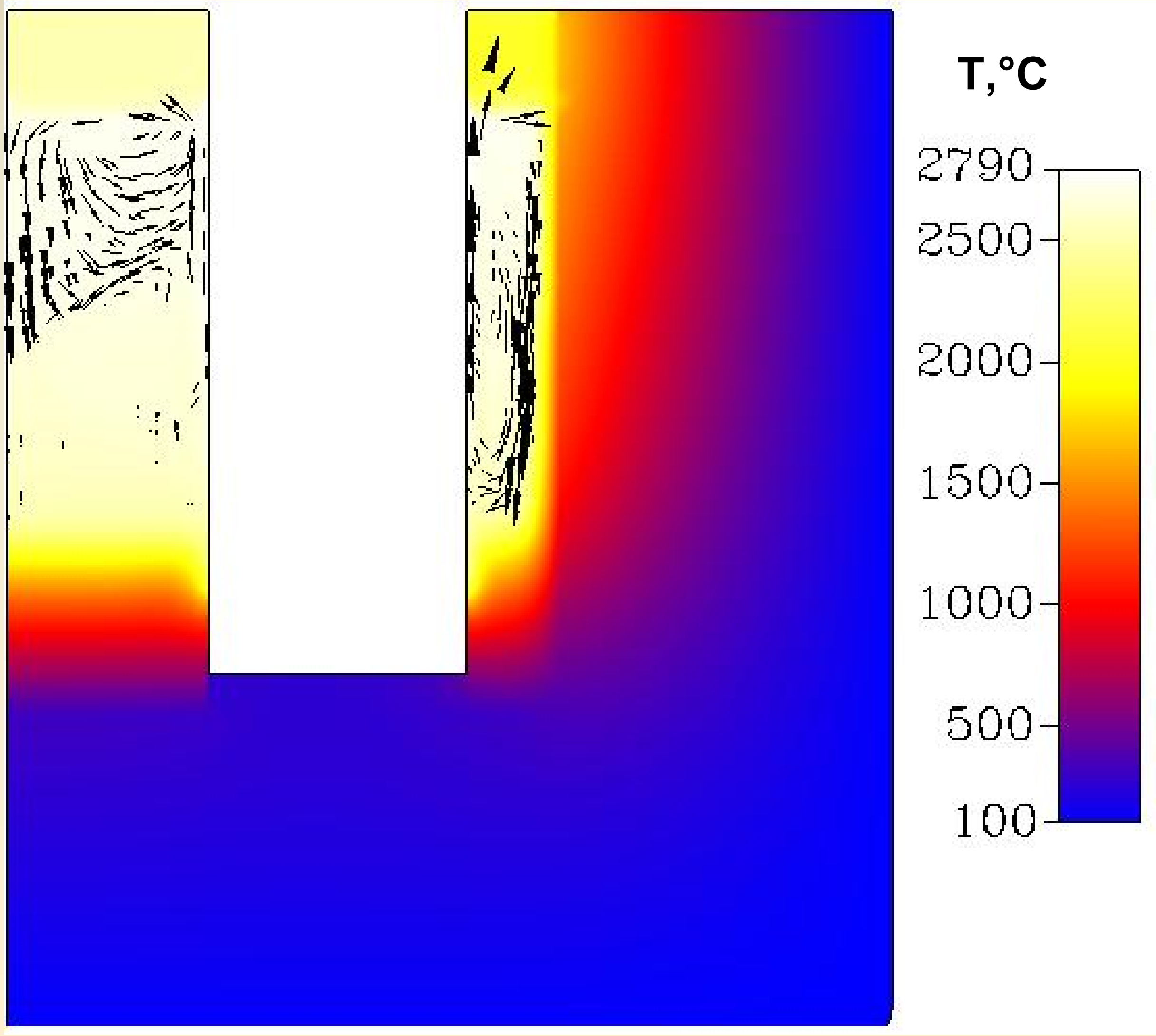
Upward surface of molten pool

Downward surface of molten pool



Cylindrical model(4)

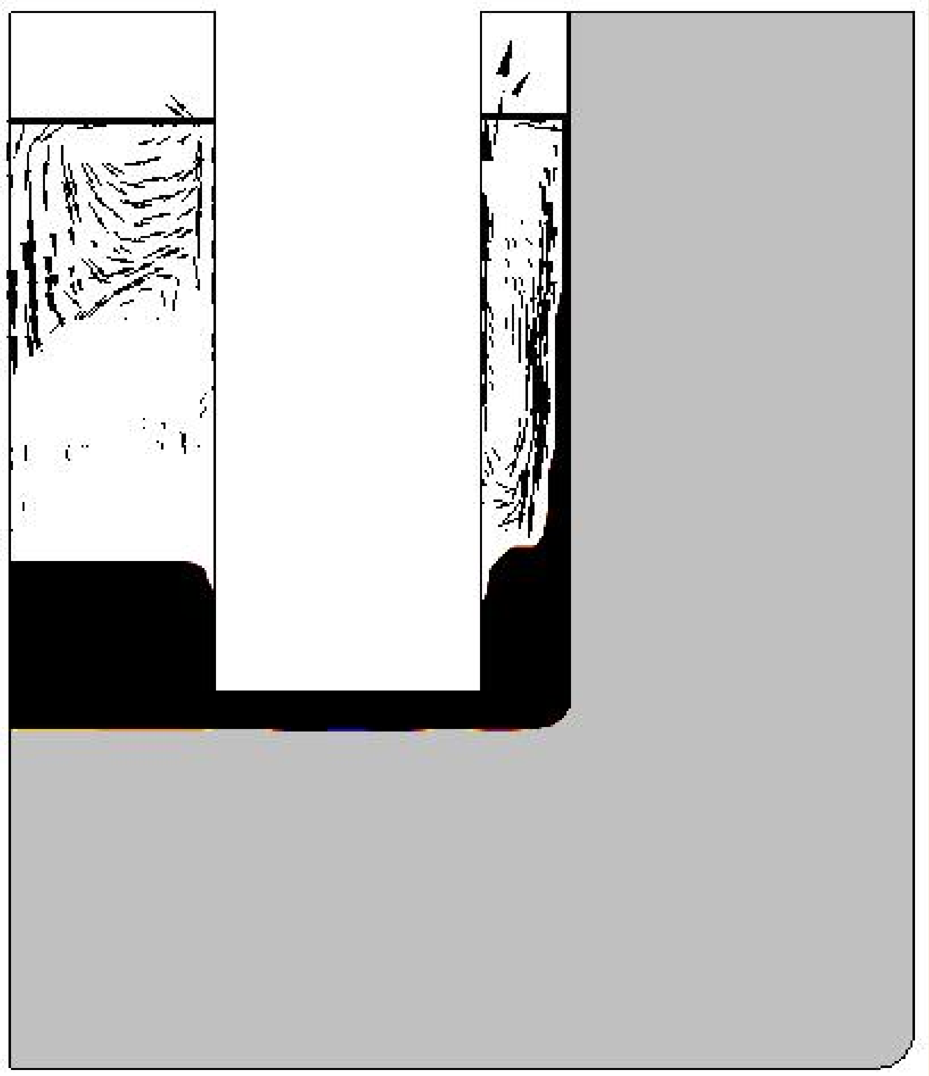
Calculation results **Temperature field in the axial section of the heater**



Cylindrical model(5)

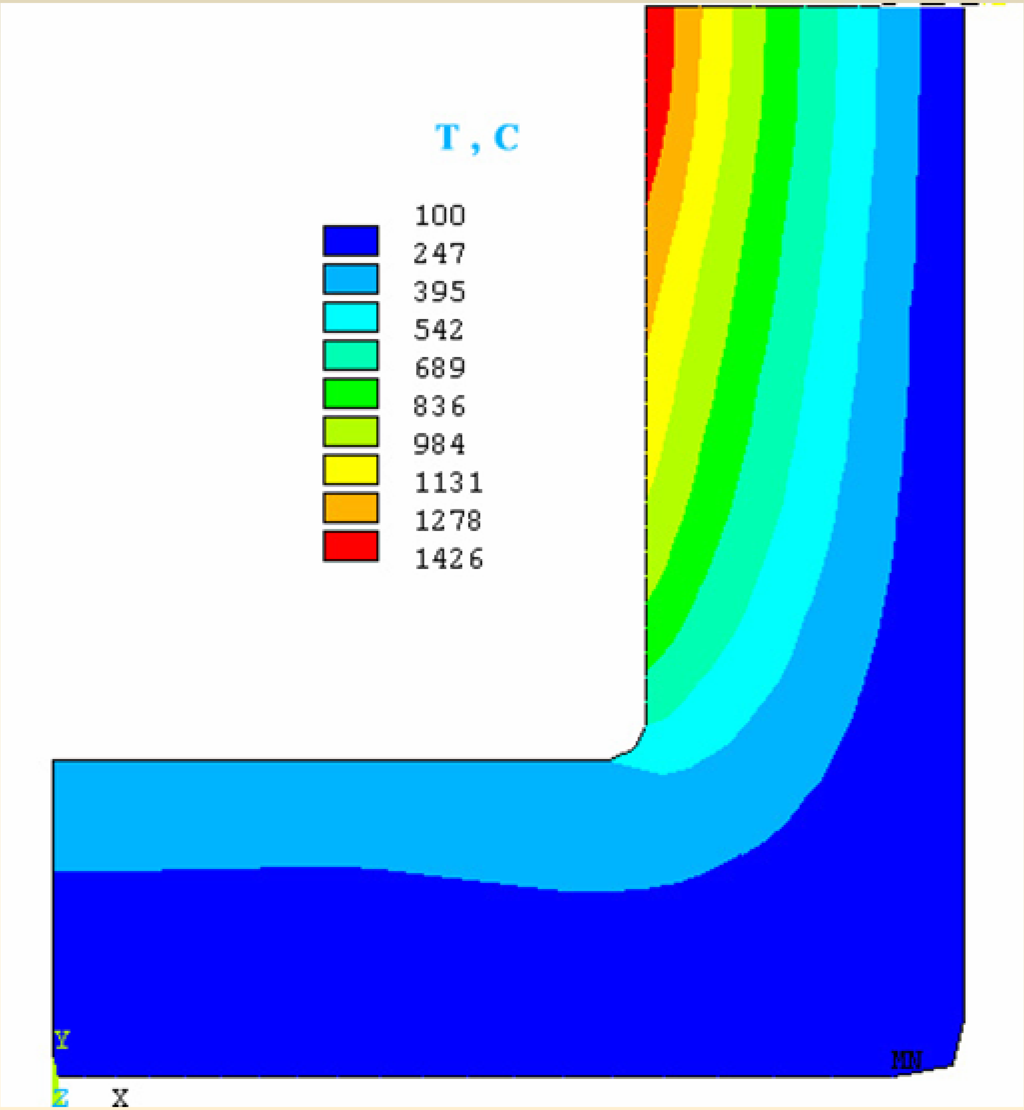
Calculation results

Crust thickness in the axial section of the heater



Cylindrical model(6)

Temperature field if the model wall thickness is 80 mm



Cylindrical model(7)

Main results of alternative model calculations

- ✓ Small azimuthal divergence of calculated parameters: crust thickness, distribution of temperatures and heat fluxes, etc. in comparison with the basic model
- ✓ Fraction of molten corium is larger in comparison with the basic model
- ✓ This model geometry enables to use electrodes having a longer heating part than in the basic version
- ✓ High temperature of the internal surface in the vessel top even in absence of external insulation. A certain wall superheating above the melting temperature can be avoided by the wall thickness reduction

Note: Model is easier to manufacture

Conclusions

- Due to the inherent limits on the power and number of electrodes the semi-elliptical model is not suitable for the preparation of a realistic pool
- Partial thermal insulation of the external wall enables to raise temperature on the internal surface to the necessary level but does not influence the molten pool configuration and volume
- Quasi-slice geometry does not provide the cardinal solution of the existing problems
- Of the considered options the cylindrical model can be recommended