Thermal Field Modeling of Spent Fuel Transport Container C-30

Juraj Václav, Mária Čarnogurská, Tomáš Brestovič

International Conference on Management of Spent Fuel from Nuclear Power Reactors - An Integrated Approach to the Back-End of the Fuel

IAEA, Vienna, Austria, 15–19 June 2015.

Nuclear facilities in the Slovak Republic

Introduction

- The use of nuclear energy started in Slovakia in 1972. Spent fuel was transported to former Soviet Union. Since 1987 all spent fuel is being stored in Interim Spent Fuel Facility at Bohunice site before its final deposition or reprocessing.
- During transport and storage of spent nuclear fuel we have to ensure three main functions of transport and storage facilities:
  - ensure subcriticality,
  - ensure protection against radiation and protection of environment, and
  - ***ensure residual heat removal***.
- Presentation describes the evaluation of modeling and calculation of thermal field for transport container C-30.

Transport container C-30

Thermal calculation 1986

- Original technical documentation contains thermal calculations of the container in Volume III.
- For calculation it was considered transport of 30 spent fuel assemblies with total residual power of 5, 8, 12 and 15 kW for wet transport and 5 and 8 Kw for dry transport.
- The calculation showed that the most dangerous transport conditions are low ambient temperature and low heat output.
- Such conditions may cause water freezing which could damage the fuel assemblies or even the transport container.

Thermal calculation 1986

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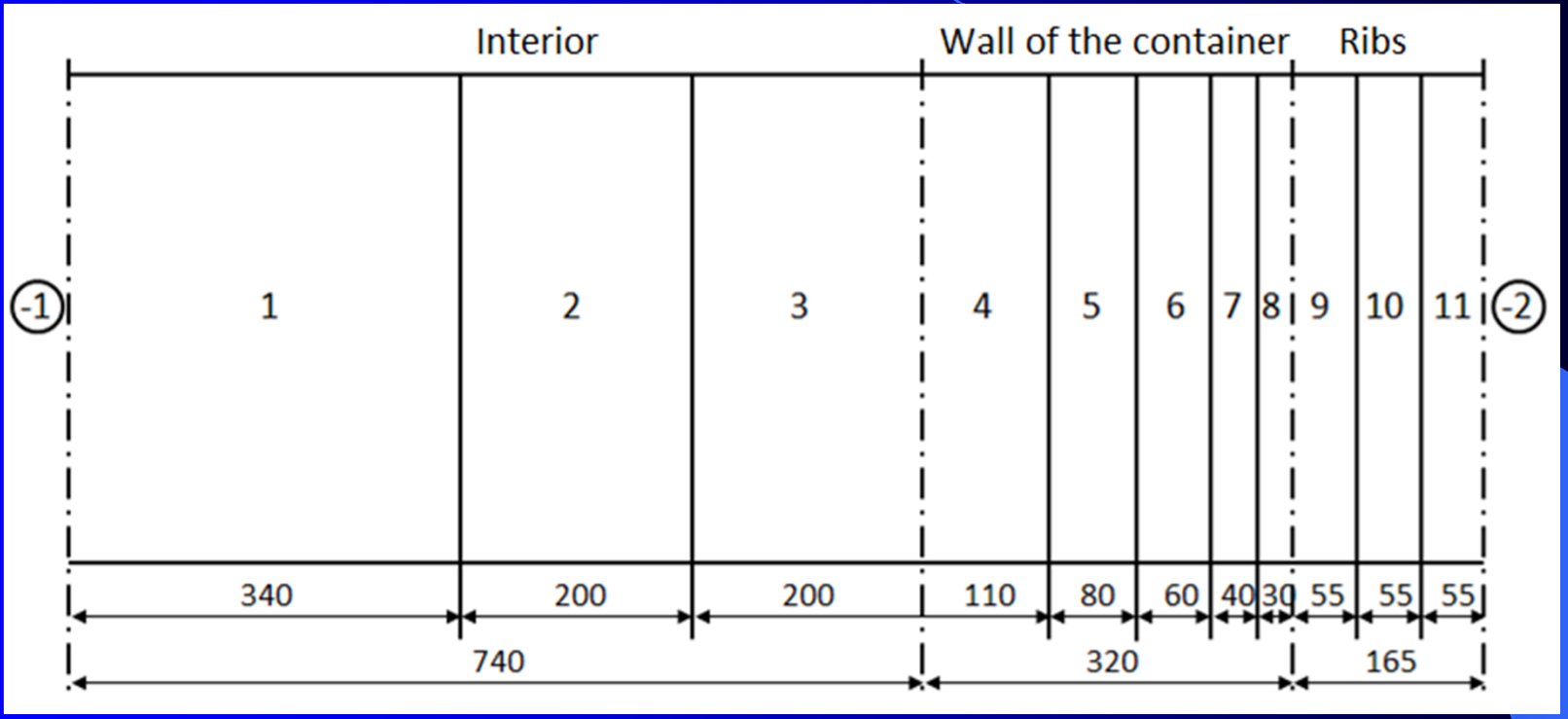
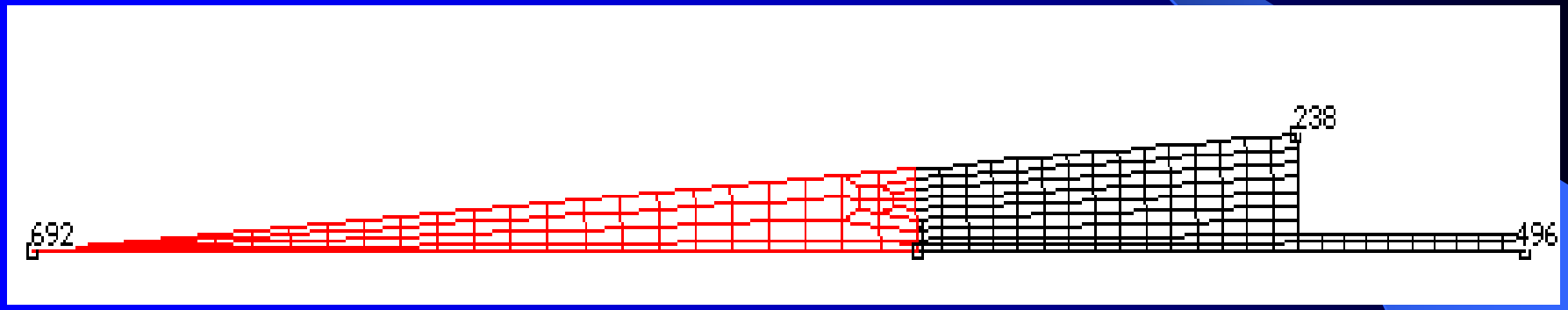


- Elements 1 to 3 represent the interior of the container, elements 4 to 8 represent the wall and elements 9 to 11 represent ribs of the container. -1 in circle represents the axis of symmetry and -2 in circle represents environment.

Thermal calculation 2002

- For purposes of thermal analysis of transport container C-30 a 2D model was evaluated.



- The model represents a horizontal cross-section of container the place with the most adverse foreseeable temperature distribution
- Model consists of a total of 262 eight-node quadratic elements related to the 889 grid points.

Thermal calculation 2002
(continued)

- Based on the described 2D model temperature of the container wall and inventory were calculated under normal conditions of transport and test conditions as required in legislative in force. The calculations gave the following results:
  - For ambient temperature + 38 °C, wet transport, with considering sunlight, KZ-48 cask, the maximal heat output is limited by maximal surface temperature + 85 °C by 24 kW.
  - For ambient temperature – 40 °C, wet transport, maximal transport velocity 100 km per hour and heat output below 15 kW, water will freeze inside the container.
  - For overheating test with ambient temperature + 38 °C, the transport container is exposed for 30 minutes to the temperature 800 °C, and then it is naturally cooled for 24 hours considering sunlight. Maximal temperature is reached at the end of overheating respectively during the cooling phase.
  - In terms of meeting the requirements of the thermal stability of the container under normal transportation conditions at ambient temperature + 38 ° C, the maximum permitted residual power of spent fuel is set to 24 kW.

Thermal calculation 2002
(continued)

- Maximal spent fuel heat output in transport container C-30 is 24 kW. For ambient temperature – 40 °C, wet transport, maximal transport velocity 100 km per hour, and heat output below 15 kW, water will freeze inside the container, what could lead to the damage of container due to brittle fracture and loss of tightness.

Thermal calculation 2009

- The analysis was performed by the computer code COSMOS.
- The calculations verify the maximum total residual power 24 kW.
- 3D geometrical model of the container was developed for the calculation purposes.
- The inventory of the container was considered as a homogenous entity with an internal heat source.
- Thermal analysis of transport container C-30 was implemented as a stationary task.
- Model has around 450,000 nodes and 300,000 elements.

Thermal calculation 2009

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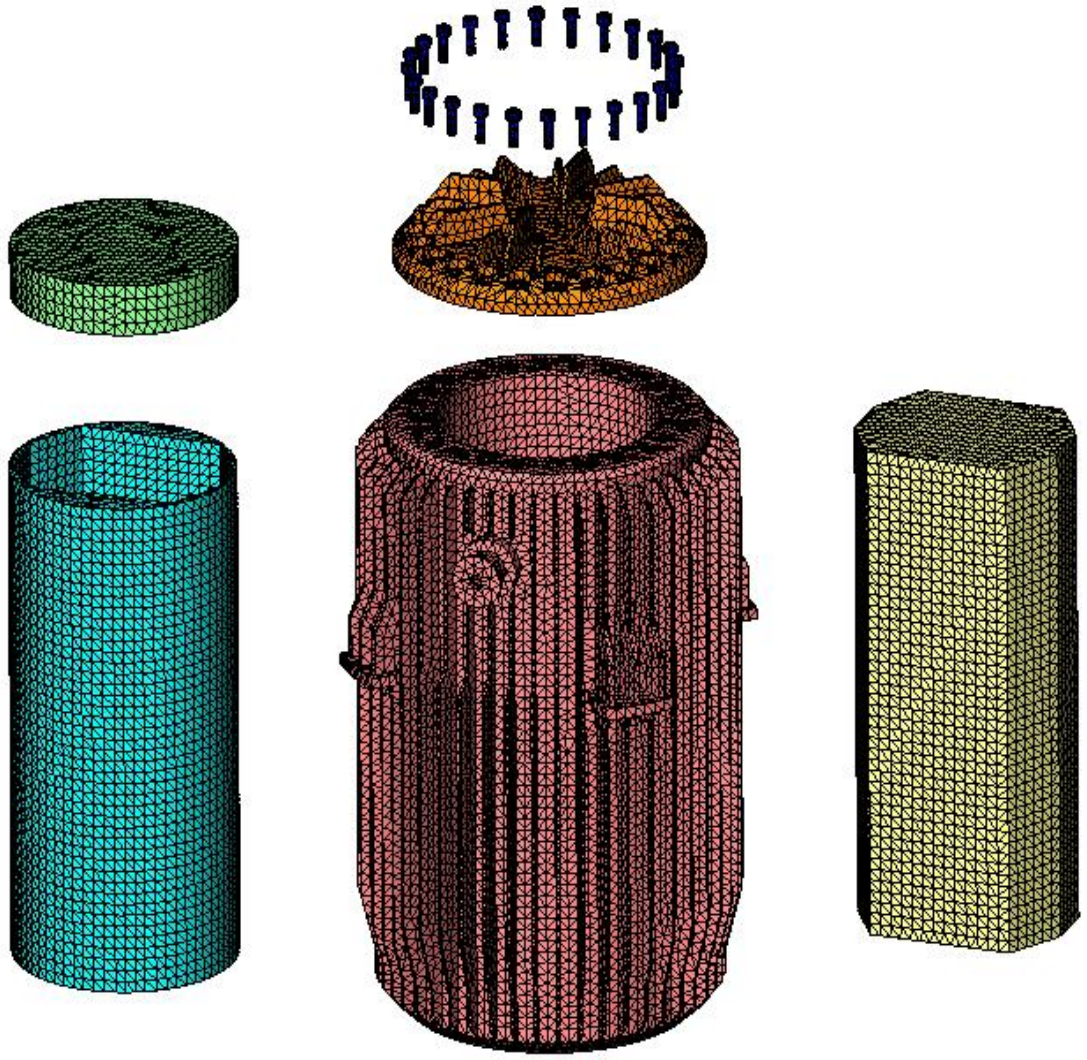

Thermal calculation 2009
(continued)

- Following simulations were performed:
  - Container in an environment with a temperature of + 38 °C. Maximal surface temperature by heat output 24 kW does not exceed 85 °C. In this case the maximal temperature of fuel cladding is 118 °C. Figure 5. shows temperature of individual parts of the container.
  - Container in an environment with a temperature of – 40 °C. When transporting the container on the wagon by ambient temperatures of – 40 °C, and heat output below 15 kW, the temperature of the coolant falls under 0 °C. This results in a local freezing of the cooling water in the container.
  - Container in an environment with a temperature of + 38 °C, considering sunlight with heat flux 800 $W \cdot m^{-2}$ for 12 hours.
  - Container in the flame with a temperature of 800 °C for 30 minutes followed by stay in an environment of + 38 °C and exposed to the sunlight for a period of 6 hours with a heat flux of 800 $W \cdot m^{-2}$. During a cooling phase the maximal temperature of fuel cladding does not exceed +187 °C.

Thermal calculation 2009
(continued)

- Numerical analysis shows that the maximum inventory temperature does not exceed at any operating, conditions or thermal tests, the value of +283 °C.
- Given the fact that the maximum permissible temperatures of fuel pins is +750 °C, it can be concluded that during transportation of fuel assemblies with a total residual power 24 kW none thermomechanical damage to fuel rods occurs.

Thermal calculation 2014-15

- The main difference between 2009 and 2014 – 15 3D model consists in the way of modeling the inventory of the container.
- In all previous calculations the inventory was considered as a homogenous entity with heat source.
- The 2014–15 3D model is more complex and it models in a simply way fuel assemblies as well as a cooling medium flow.
- The central circular part represents the area of water between fuel pins. This part does not produce any heat.
- The rest of the assembly is bordered by hexagon on the outer periphery and by a circle inside of the fuel assembly. Only this part is responsible for heat production.
- The model takes into consideration also the coolant (water) flow.
- The model consists of more than 9,000,000 tetrahedrons.

Thermal calculation 2014-15

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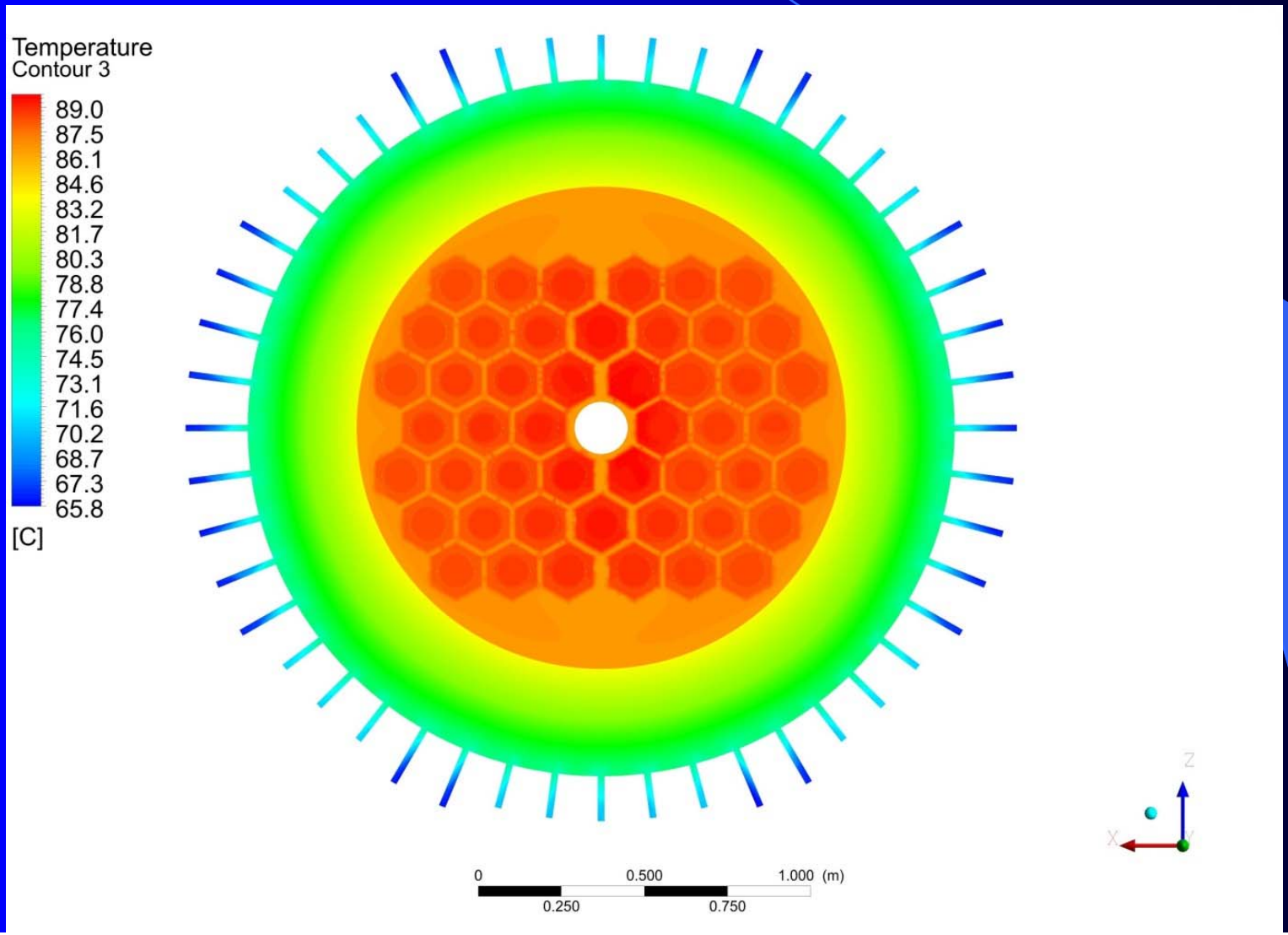

Thermal calculation 2014-15

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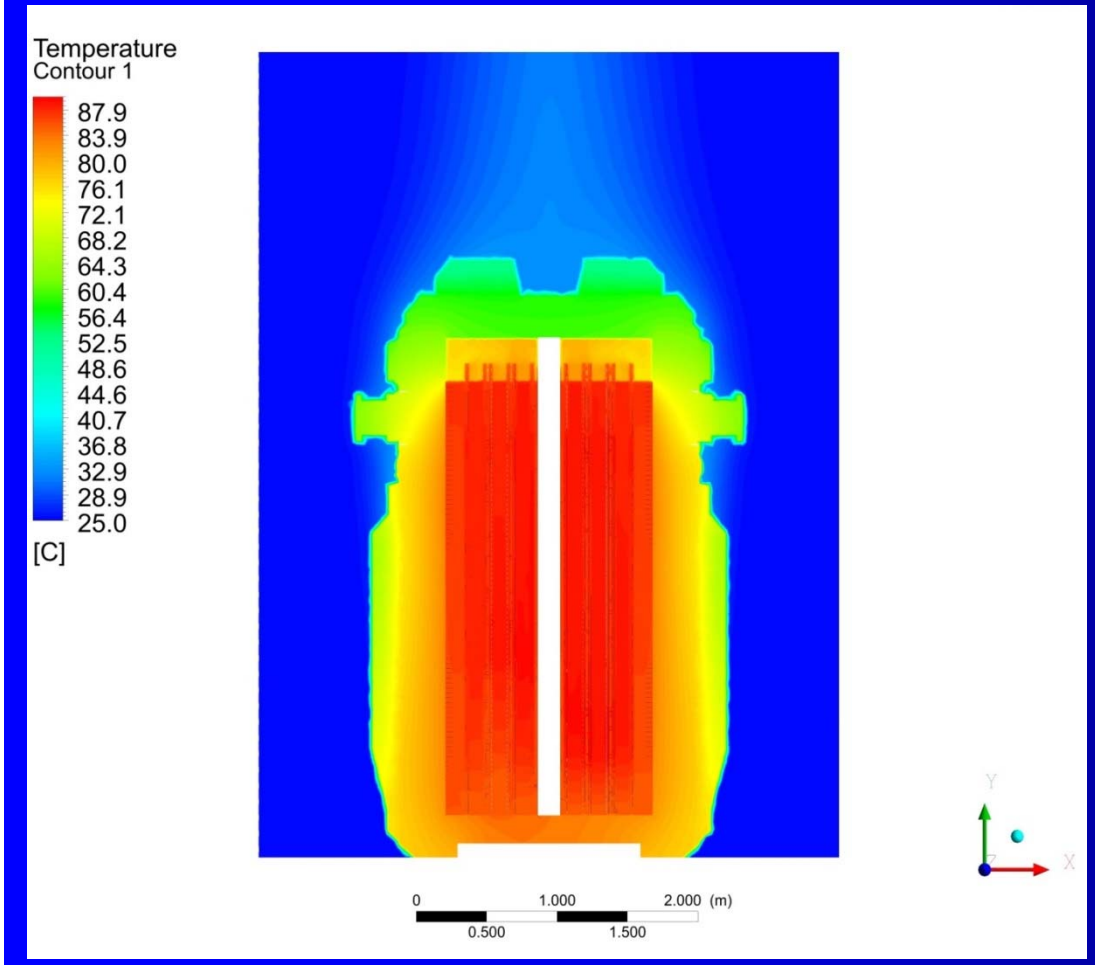

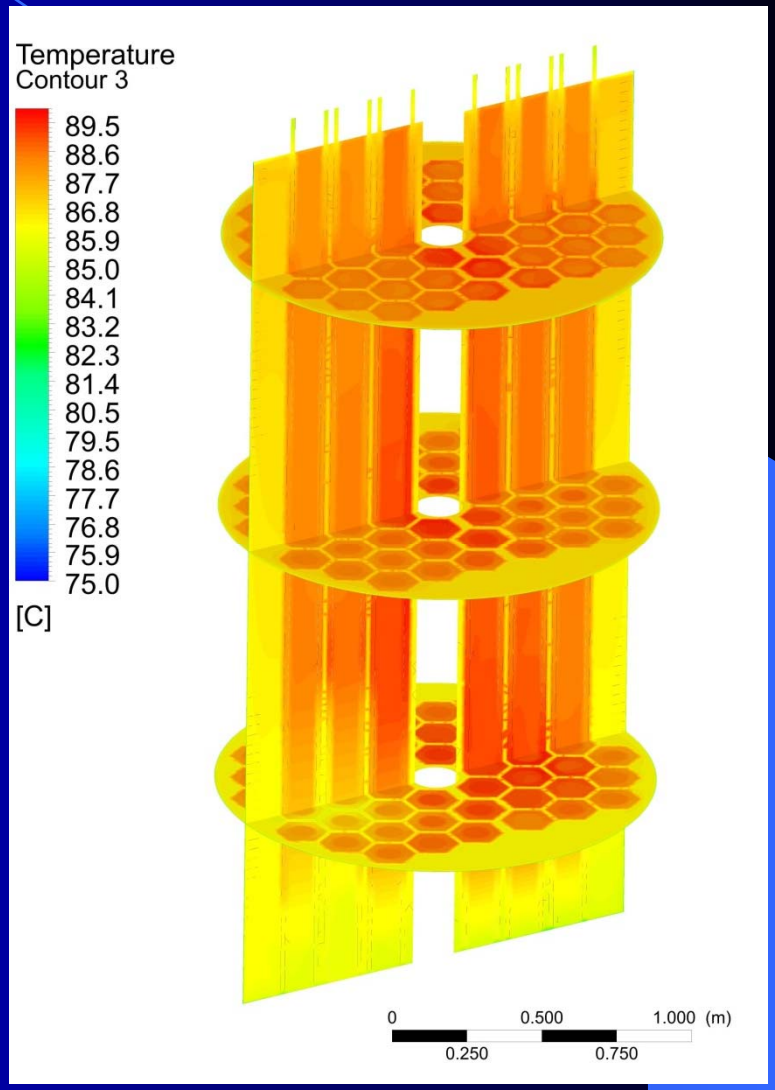

Thermal calculation 2014-15
(continued)

- As for now only basic calculations have been made.
- As the model consists of more than 9,000,000 tetrahedrons, each calculation needs quite a long time – days even weeks.
- Full results will be available by the beginning of the next year.

Conclusions

- The aim of thermal calculations of transport container is to prove that residual heat produced by spent fuel could be safely led away without any damage to the fuel and to the container.
- First calculations were made thirty years ago. We can see that improvement of computing power allows creating more complex geometrical models of the container.
- During last years also the enrichment and burnup of the nuclear fuel has increased.
- All this facts cause the need for further, more detailed analysis of the inventory of the transport container C-30.

Thank you for your attention!