Three-dimensional calculations with CFD codes and HPC in nuclear power engineering

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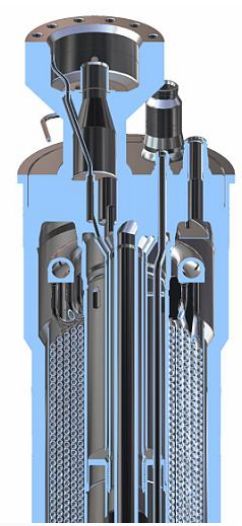
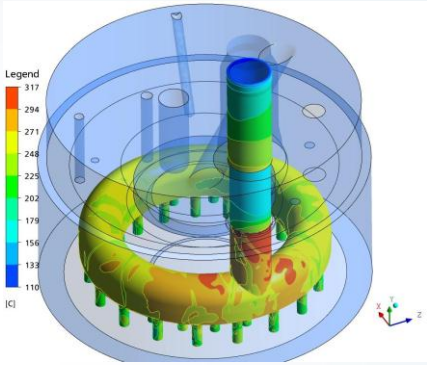
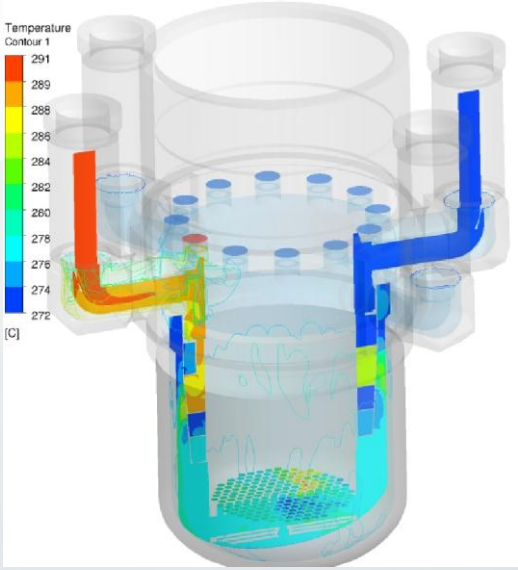
1. The purposes of CFD codes use

1. Numerical simulations for a proper evaluation of thermal fatigue (unsteady heat loading in unsteady mixing zones of flow streams at different temperatures, which can lead to material failure)





2. Numerical simulations of mixing phenomena occurring in the downcomer and lower plenum of the reactor in the case of asymmetric loop-flow conditions in terms of temperature.



1. The purposes of CFD codes use

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Laboratory for Thermal-Hydraulics
Nuclear Energy and Safety Department

Post-Meeting (1)

7. Overall Priority Ranking (Single-Phase)

Topic (single-phase)	Score/36	Generic Interest
PTS	31	HIGH
Hydrogen mixing and combustion in containments	31	
Flows in complex geometries*	29	
Boron dilution	28	
Sump strainer clogging	26	
Aerosol deposition in containments	26	
Thermal fatigue	23	MEDIUM
MSLB (leading to asymmetric flow)	22	
Hot-leg heterogeneities	21	
HTGR lower plenum mixing	16	
HTGR core heat transfer	15	
HTGR reactor cavity cooling heat transfer	13	LOW
GCR/VHTR heat transfer issues	12	
Flow behind blockages in LMFRs	9	
Flow-induced vibrations in LMFRs	8	
Core barrel vibration in APWR	6	

2. Specific features of CFD codes use in nuclear power engineering

ОКБМ АФРИКАНТОВ
ПРЕДПРИЯТИЕ ГОСКОРПОРАЦИИ «РОСАТОМ»

Specific	Method of the account
Anisotropic turbulence due to different geometrical scales	Use of Scale-Resolving Simulation (SRS) models in CFD
High priority of numerical simulations of mixing phenomena	Use of Scale-Resolving Simulation (SRS) models in CFD
Sufficient influence of buoyancy effects	?

2. Specific features of CFD codes use in nuclear power engineering

ОКБМ АФРИКАНТОВ
ПРЕДПРИЯТИЕ ГОСКОРПОРАЦИИ «РОСАТОМ»

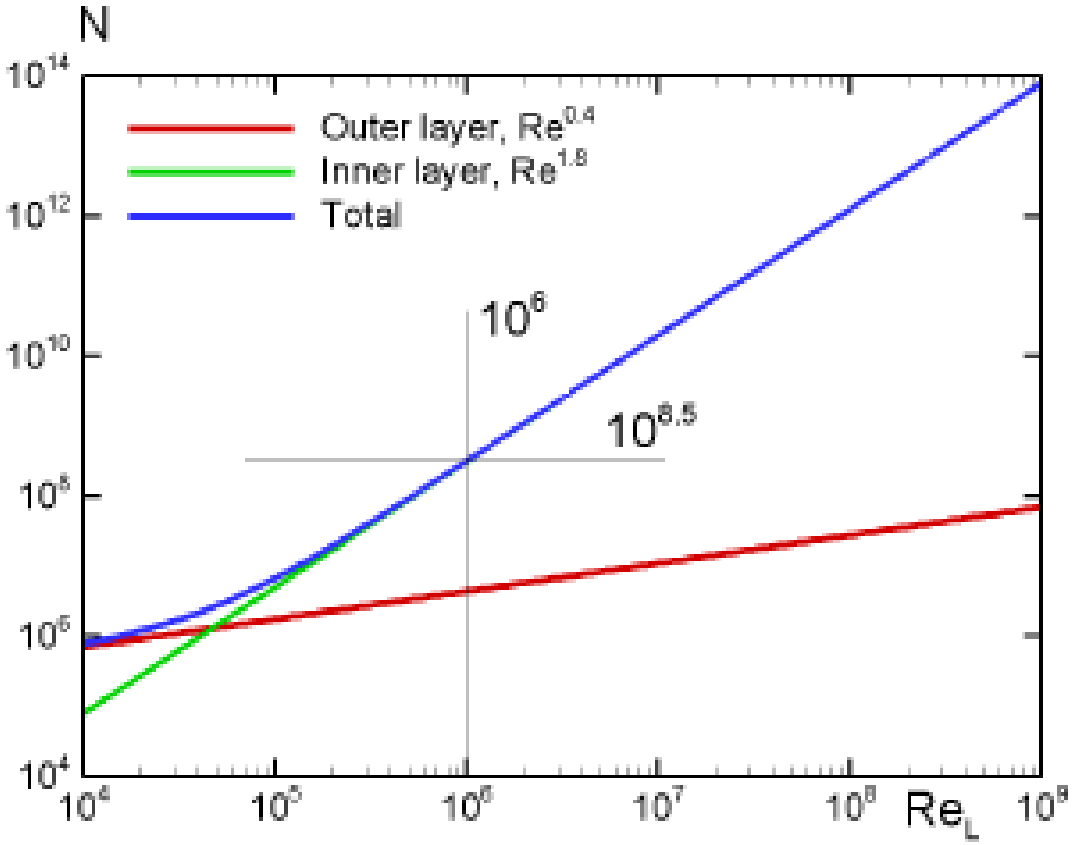
Use of Scale-Resolving Simulation (SRS) models in CFD

Formally demands the increasing of dimension of a problem ~ in 1000 times, and calculation time - ~ in 50 000 times

It's impossible now even using HPC

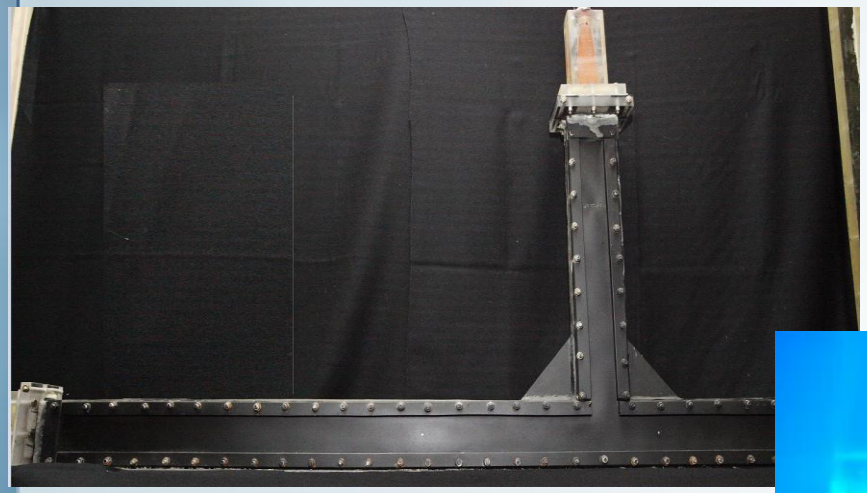
The possibilities of SRS models in CFD for providing the adequate description of NRS problems should be confirmed experimentally

2. Specific features of CFD codes use in nuclear power engineering



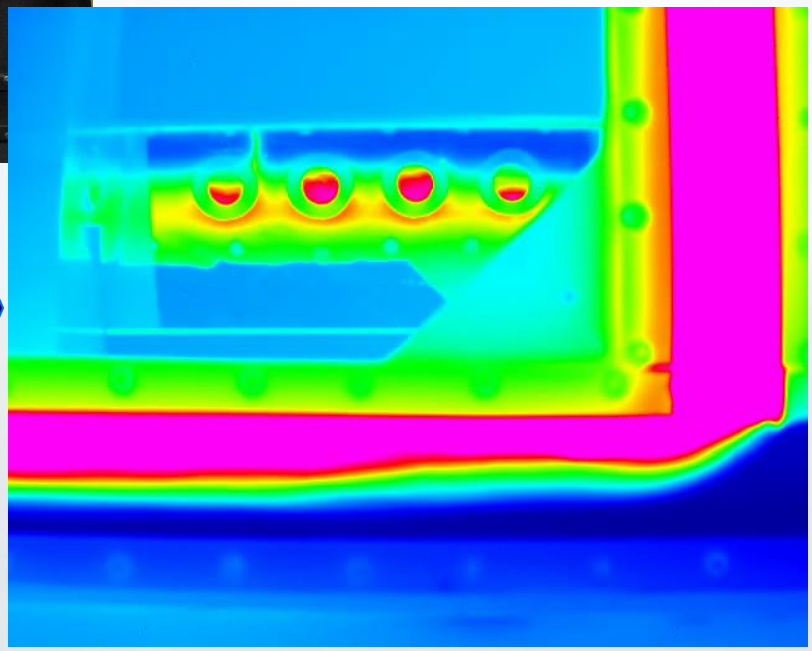
2. Results of CFD codes validation

Mixing of not isothermal flows



Test facility

Measurements with infra – red camera

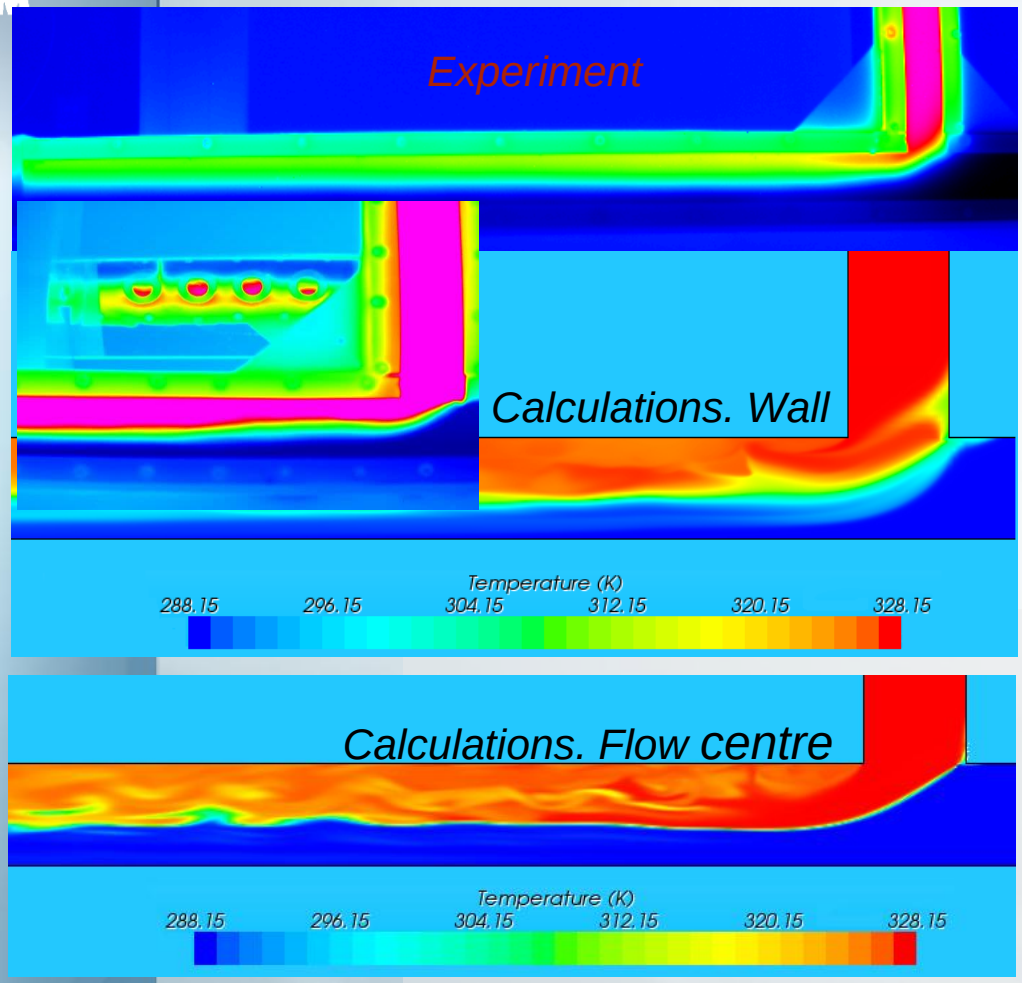


Flow velocities:
Cold water - 0,5м/s
Hot water - 0,5м/s
Re_{outlet} = 46000

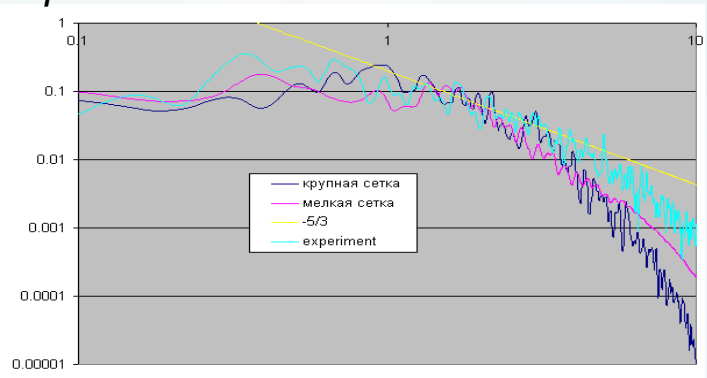
Flow Temperatures:
Cold water – 15 ºC
Hot water – 55 ºC
Transient duration – 30c

2. Results of CFD codes validation

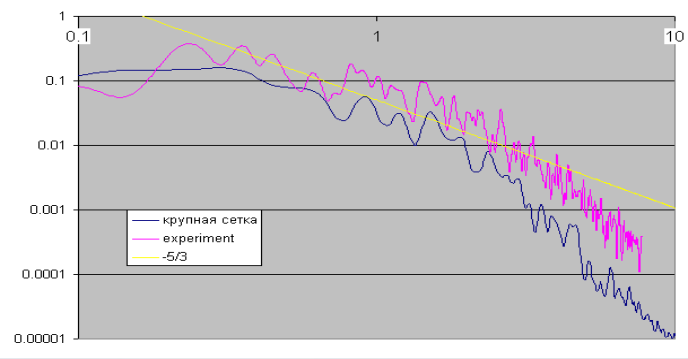
Mixing of non isothermal flows



Wall temperature pulsations spectrum on distance 3D

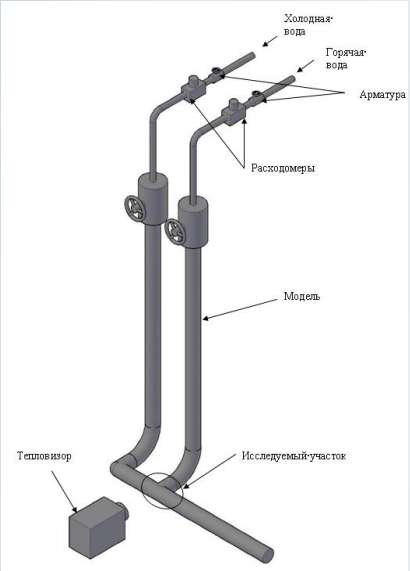


Temperature pulsations spectrum on distance 6D. Flow centre

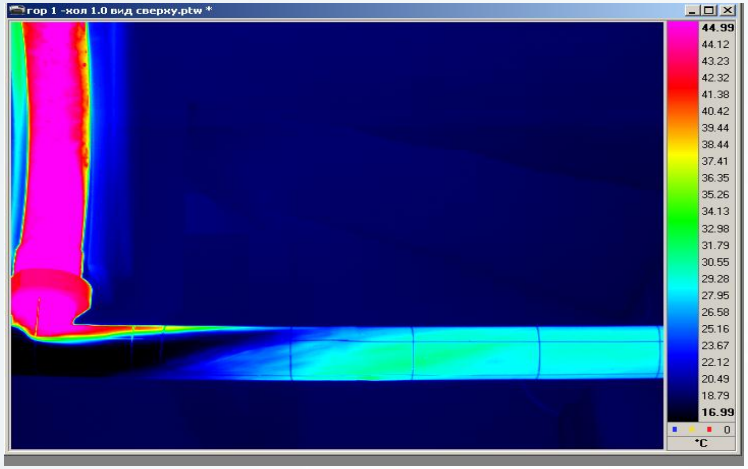


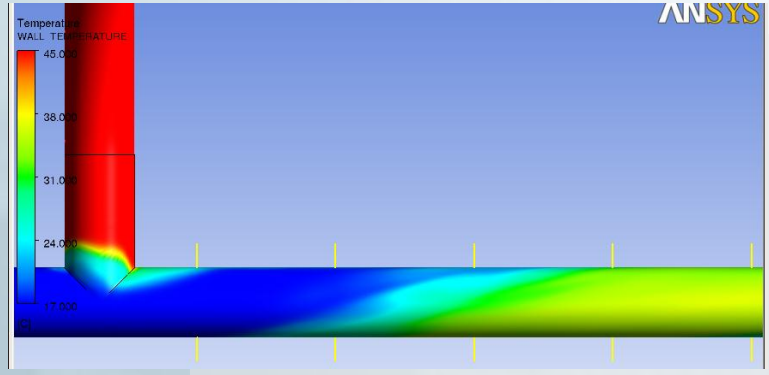
2. Results of CFD codes validation

Test facility



Experimental results





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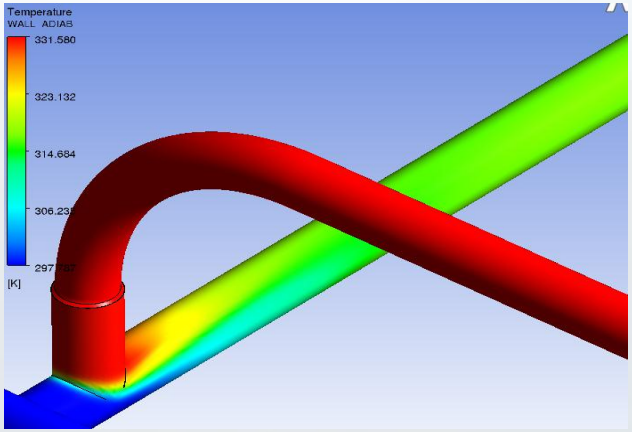
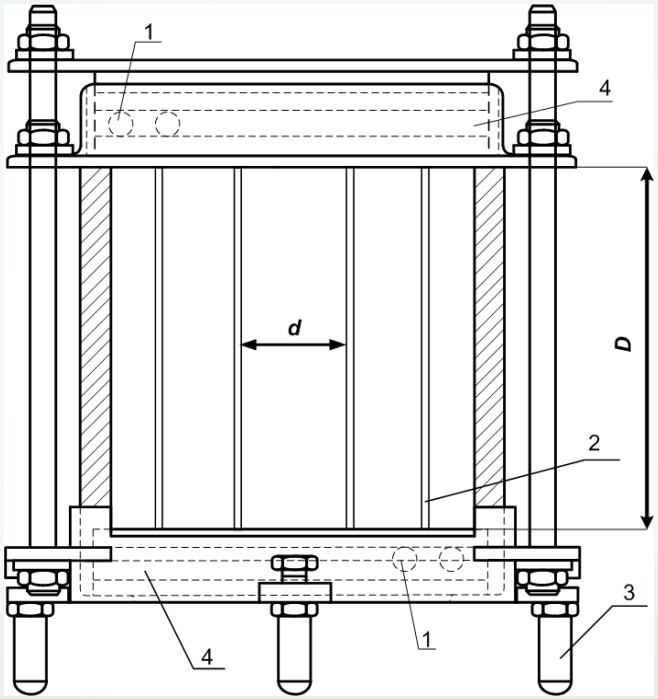


RANS

2. Results of CFD codes validation

General view of experimental model

The sketch of experimental model



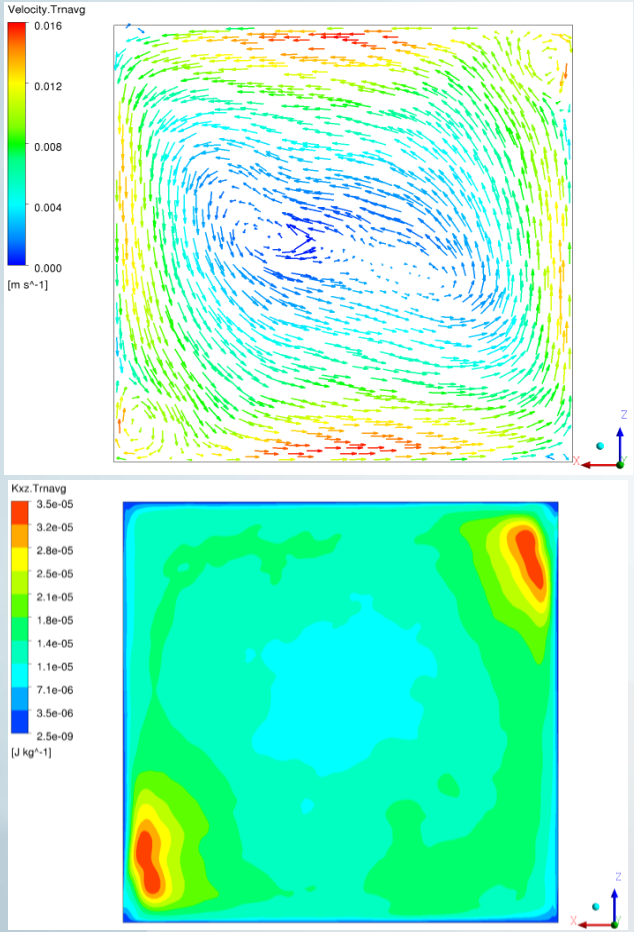
1 – heat exchanger tubes of a heater and a refrigerator; 2 – Vertical partitions; 3 – Legs; 4 – heat conductive plate

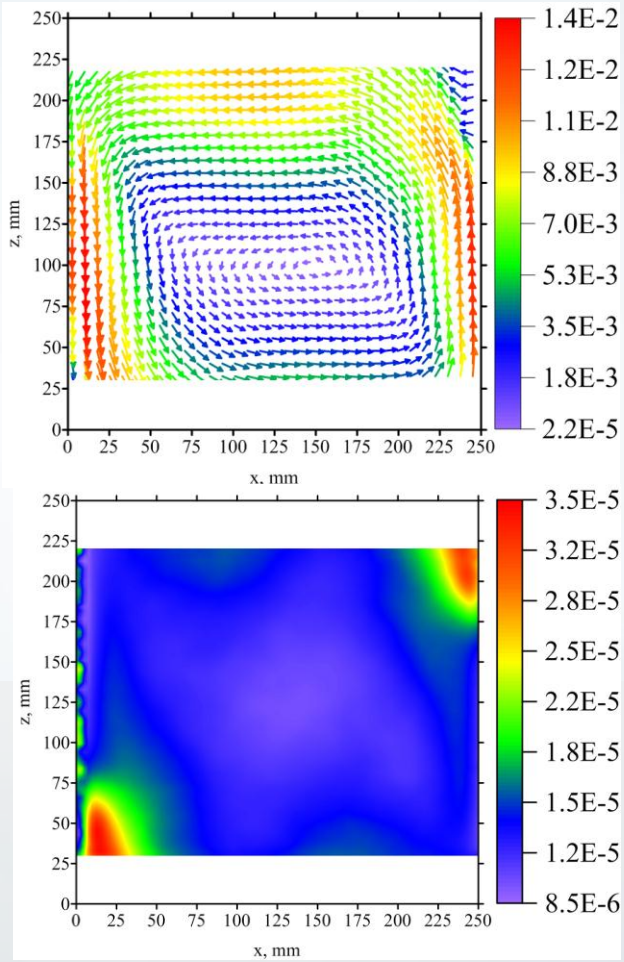
In the experiment constant values of temperatures of a heater and a refrigerator under the law are provided:

$$T = T_{OC} \pm \Delta T/2, \quad T_{OC} - \text{Ambient temperature};$$

$$\Delta T = 10^0 C$$

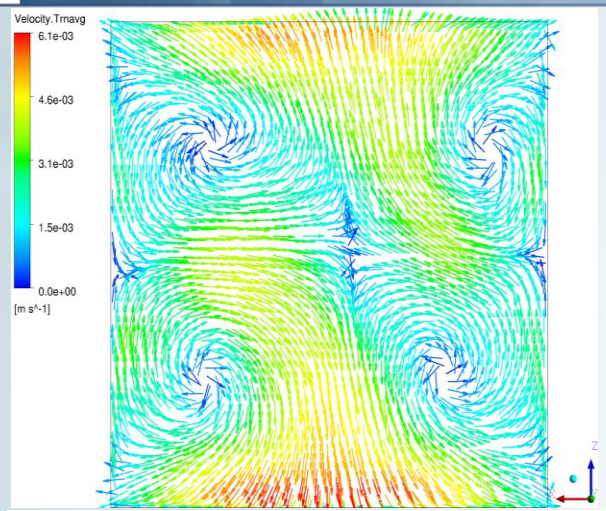
2. Results of CFD codes validation

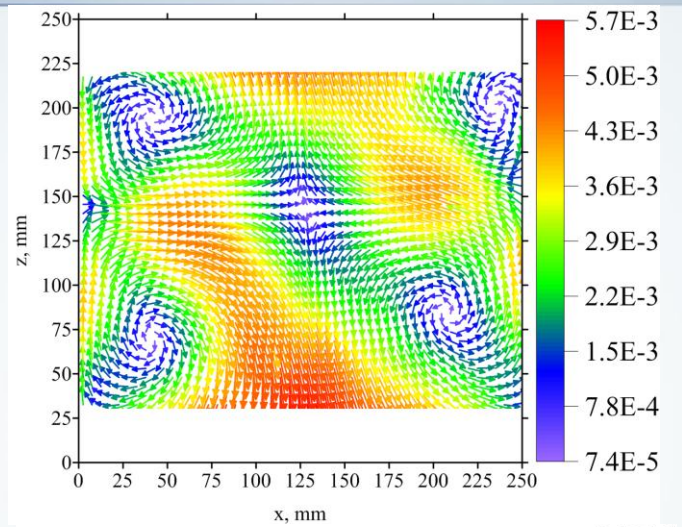


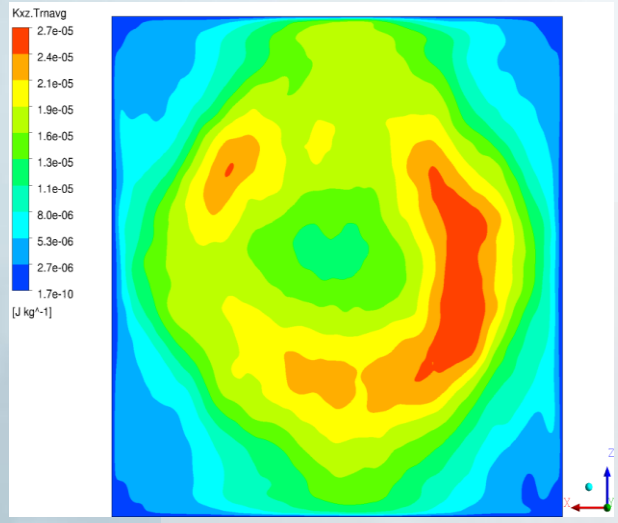


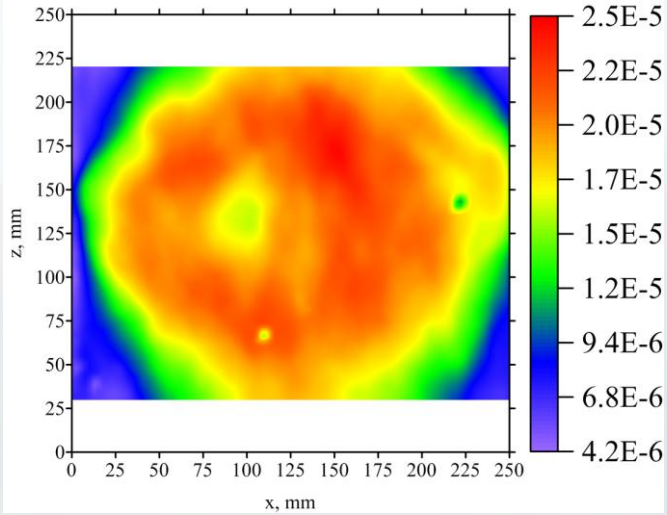
Average field of speed (above) and density of turbulent pulsations energy (below) in the central vertical section of a cubic cavity (Γ=1). Calculation (at the left) and experiment (on the right).

2. Results of CFD codes validation



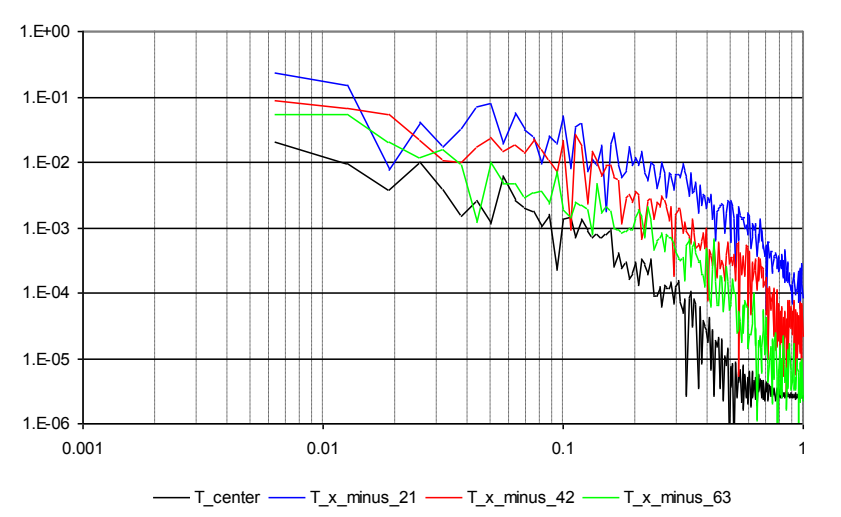


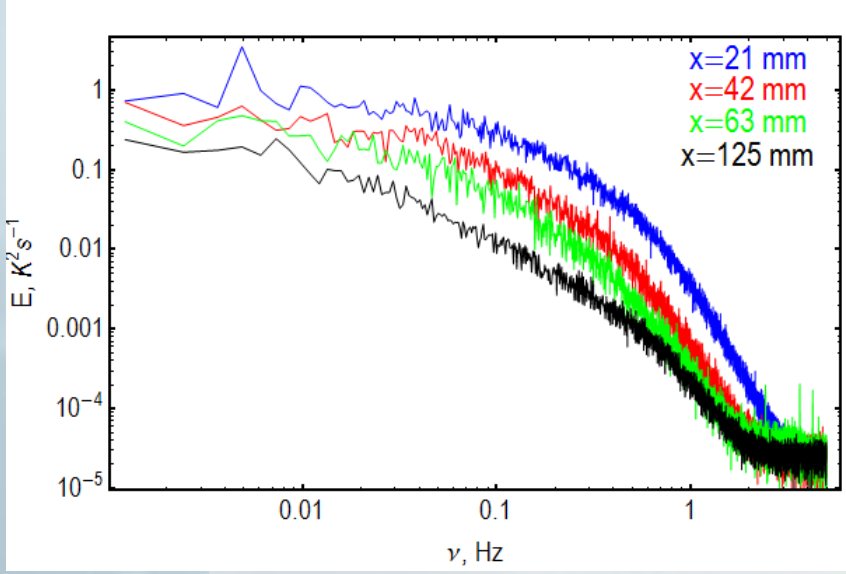




Average field of speed (above) and density of turbulent pulsations energy (below) in the central vertical section of a thin cavity (Γ=1). Calculation (at the left) and experiment (on the right).

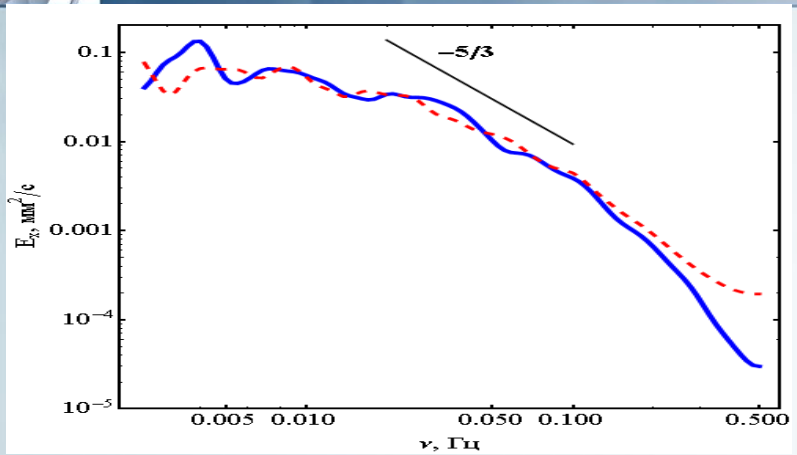
2. Results of CFD codes validation

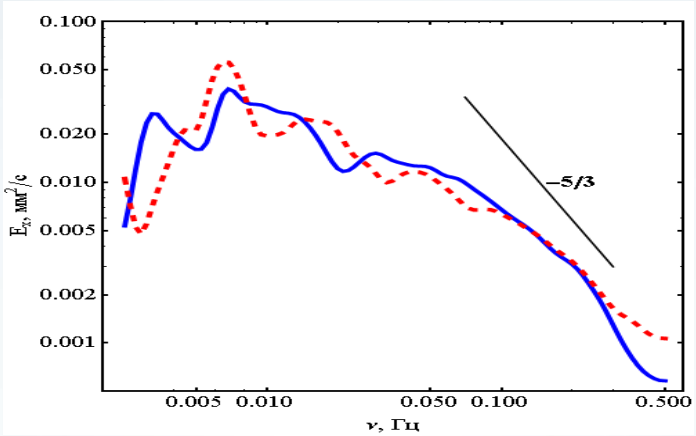


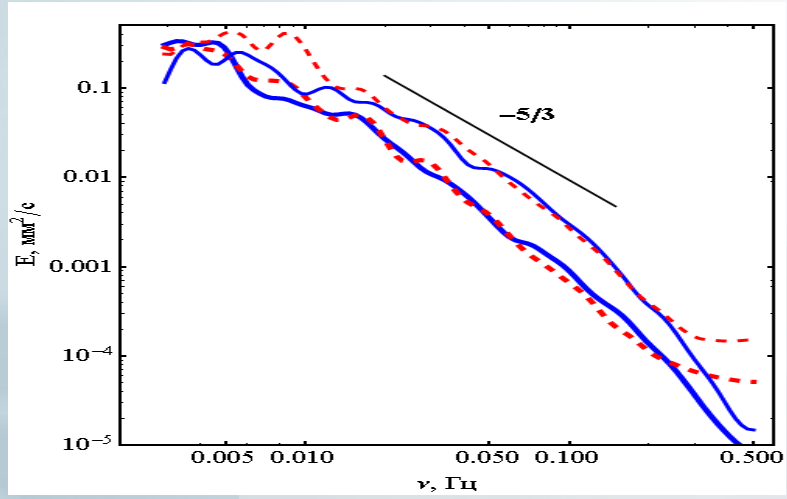


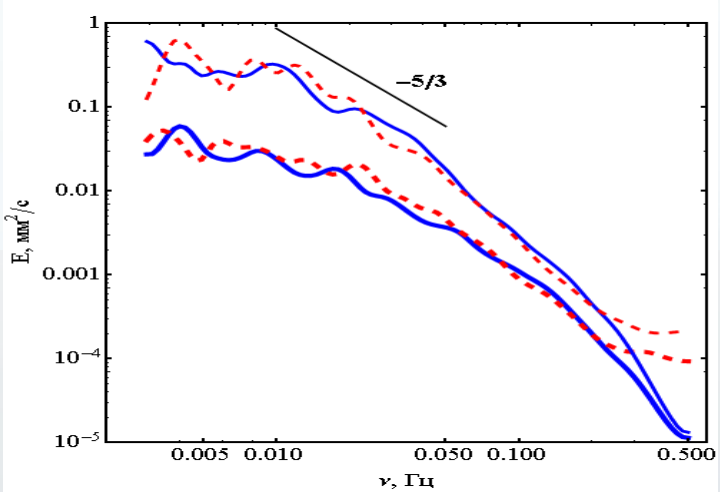
Spectral density of temperature pulsations energy in four points of a cubic cavity (on distance 21, 42, 63, 125 mm from the center of a lateral side). Calculation (from above) and experiment (from below).

2. Results of CFD codes validation









Spectral density of speed pulsations energy in the center of a cavity (at the left) and on distance 21мм from a lateral wall (on the right) cubed (above) and cracks (below). Calculation-continuous lines, a dotted line – experiment; vx – thick lines, vz-thin lines.

3. The requirements for HPC computers

HPC computers should be adapted for CFD codes usage:

Required mesh size - 10^{10}

Required cores number in HPC computer – 10^5

Unlimited multi -level information storage system

5. Conclusions

1. Nuclear application of CFD codes seems very promising for solution of a wide range of application tasks.

2. Full-scale nuclear implementation of CFD codes requires high-efficiency computer power with graph units of high-volume random access memory for pre- and post-processor treatment, and multilevel information storage system.

3. It seems promising to combine computer power development with development of domestic CFD codes, adapted for nuclear task specificity and having high-degree paralleling. Such a task was solved well enough within the Project “Development of super-computers and grid technologies” approved by the Commission on Upgrade and Technological Development of Russian Economics under the President of the Russian Federation.

Thanks for attention!