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COMPUTATIONAL FLUID DYNAMIC MODEL OF TRIGA MARK II REACTOR

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ABSTRACT

The objective of this work is to build a thermo-hydraulic model of the natural circulation flow in TRIGA Mark II research reactor at the Jožef Stefan Institute (JSI) by using computational fluid dynamic (CFD) code. Indeed, CFD is a very accurate tool describing fluid flow mechanics by solving numerical algorithms.

This work is a step of a project aiming to build a computational model of TRIGA Mark II pool type research reactor coupling thermal-hydraulics and neutron physics in order to see how each one influence each other and what are the main parameters involved in this process.

Whereas TRIGA at JSI was studied in great detail from neutron physics point of view, models describing flow pattern inside the reactor tank do not exist. Indeed, such model is not needed from a safety point of view; however, the benefit of such research is to establish an accurate benchmark test for coupled thermal-hydraulics and neutronic models. Starting from a given power distribution, which has already been established as a main input from neutron physics model, output such as temperature distribution and velocity field are computed.

In the paper, the current status of the model is presented (geometry, mesh, boundary conditions…); verification and validation are made with data collected during some of the experiments performed at JSI.

1 INTRODUCTION

Research reactors are used for various purposes: education, isotope production, material sample irradiation. They are also less complex to study [1] and hence complete modelling of the system is easier to achieve.

CFD is a branch of fluid mechanics that can be helpful for studying fluid flow, heat transfer, chemical reactions etc by solving mathematical equations with the help of numerical analysis [2]. CFD employs a very simple principle by dividing the entire system in small cells. Then governing mass, momentum and energy conservation equations are applied on these discrete elements to find numerical solutions regarding velocity, pressure distribution, temperatures [3].

2 TRIGA RESEARCH REACTOR AND EXPERIMENT

TRIGA research reactor at the "Jožef Stefan" Institute in Ljubljana is a 250 kW TRIGA Mark II type reactor [4]. It is a light water reactor cooled by demineralised light water which flows through the reactor core by natural convection. The side and top views of the reactor are shown in Figure1.

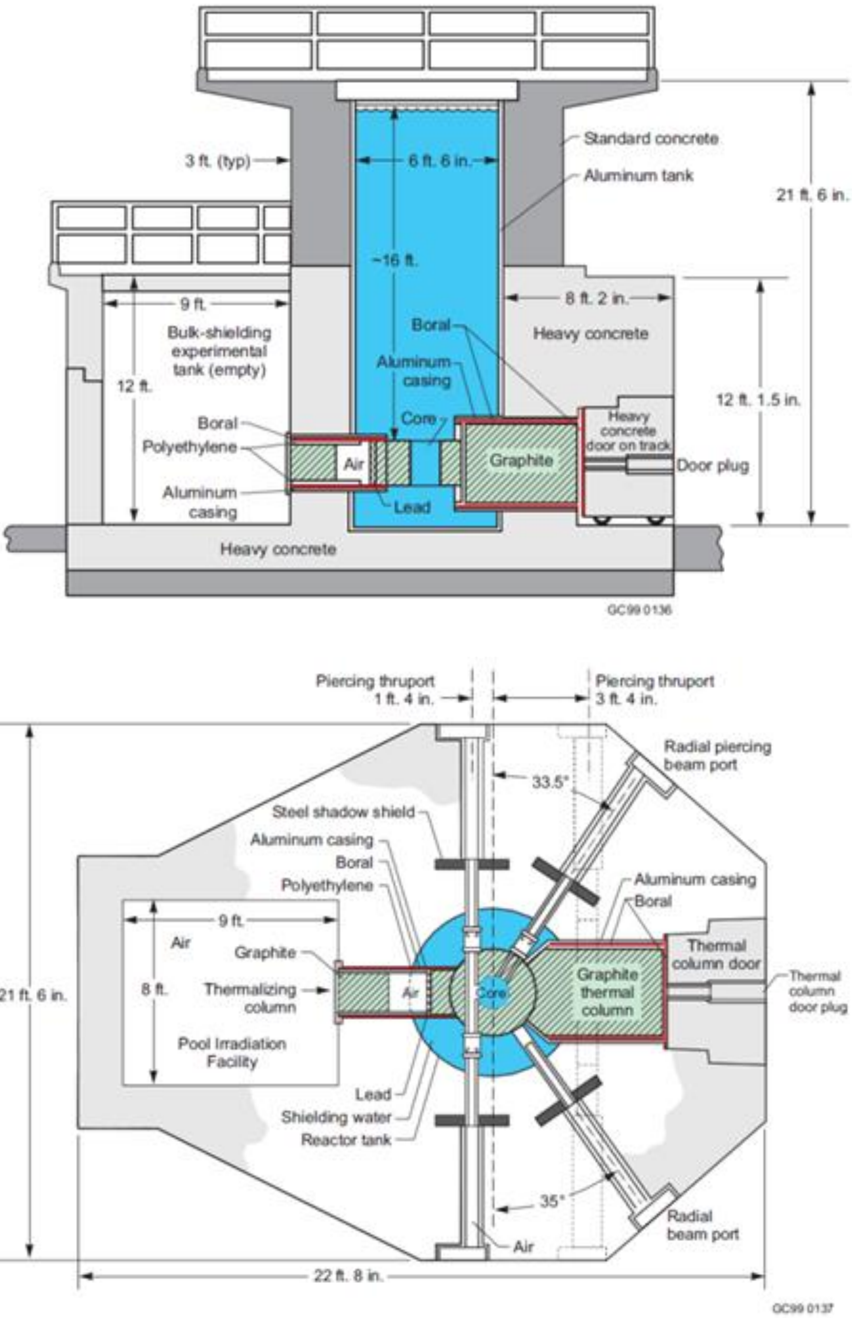

Figure 1: Side and top view of the TRIGA Reactor

The core is placed at the bottom of an open tank with 5m of demineralised water above it. The core has a cylindrical configuration with 91 locations. Each location can be filled either by fuel elements or other components like control rods, a neutron source, irradiation channels, etc. Elements are arranged in six concentric rings: A, B, C, D, E and F, having 1, 6, 12, 18, 24 and 30 locations, respectively.

Over years of utilisations, many experiments have produced data sets of various physical parameters. This paper will use temperatures that have been measured during a thermal power calibration, more details can be found in the paper written by Žagar, et al. [5].

3 METHODOLOGY

The Ansys Workbench environment with CFX code [6] was used to study our problem. This Platform, provide a link between the different software relative to the definition of a CFD simulation: creation of the geometry, meshing and set up of the physical parameter.

3.1 Creating the geometry

The First step of the simulation is to create the geometry, here, “Design modeller” was used to create the computational domain. Our geometry (Figure 2) is a cylindrical tank (6.5m high with a diameter of 2m) which contains various solid parts such as thermal columns, reflector, grids and different rods (irradiation channel, fuel, control) constituting the core. A few elements of minor importance were not modelled.

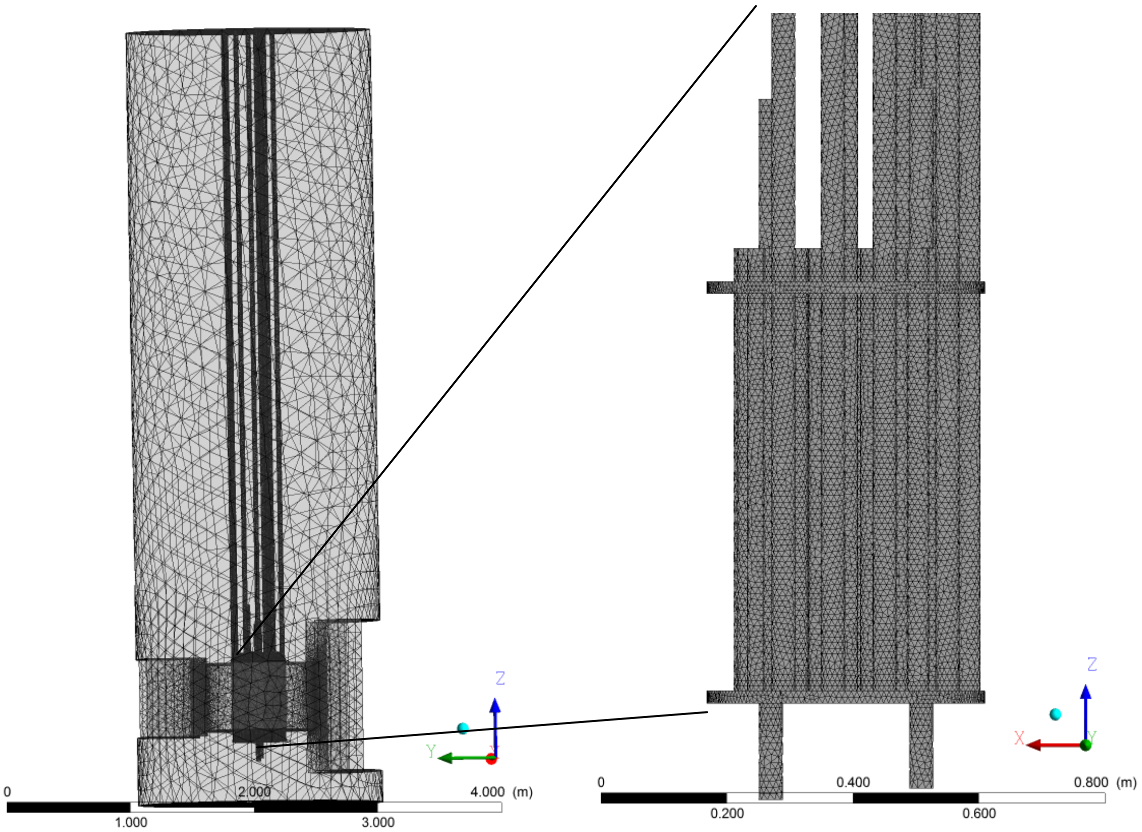

Figure 2: Geometrical model of TRIGA meshed
(pool on the left and core detailed on the right)

3.2 Generating the mesh

The second step is to subdivide the domain by generating volume element in which the governing Navier Stokes equations are discretized into a system of algebraic equations. ANSYS meshing was use to generate the different meshes (with tetrahedral elements). Mesh quality was assessed through different criteria which can be seen in Table 1.

Table 1: Mesh statistics

mesh	coarse	medium	fine
number of nodes	559 991	1 142 877	2 741 127
numbers of elements	2 894 019	5 803 774	14 001 246
Max edge length ratio	16.5436	21.3456	20.2626

After running few simulations, it appears that for this work, the coarse mesh was good enough and so in order to minimize computational time we will only consider this one from now.

3.3 Setting up the physics

Once domain is created and discretized, physics preference should be set. The pool is filled by demineralised water with classic thermodynamic properties. Buoyancy is a key mechanism cooling the core of TRIGA reactor and is modelled through Boussinesq approximation [6]. Turbulence is modelled with k-epsilon RANS model [6].

Water domain is bounded by different structures and so a set of boundary condition has to be chosen. All boundaries were set as a no slip wall. Then heat transfer hypothesis was made; during the operation, the heat is produced by the fuel, hence a function was created to describe heat flux production along the rods: it was assumed that the power is homogeneously distributed in the rods and that the axial distribution has a cosine shape. Our last assumption concerns the heat sink; it was decided that all the structures in the pool are adiabatic and so that heat was lost mainly through the concrete wall which represents the largest surface. Heat transfer coefficient was derived from Nusselt number, which was computed according to Churchill and Chu [7] correlation for a turbulent flow near the vertical surface:

$$Nu = 0.68 + 0.67(Ra\Psi)^{\frac{1}{4}}(1 + 1.6\times10^{-8}Ra\Psi)^{\frac{1}{12}}$$

Where Ra is the Rayleigh number and Ψ is a function of Prandlt (Pr) number defined as:

$$\Psi = (1 + (\frac{0.492}{\mathrm{Pr}})^{\frac{9}{16}})^{\frac{-16}{9}}$$

Then, the average heat transfer coefficient *h* can be expressed in terms of Nusselt number, fluid conductivity *k* and length *L* of the surface.

$$h = \frac{kNu}{L}$$

In our case with a Rayleigh around 10^{12} we obtain an approximate value for *h*=100 W/m²/K

In the present work, the external cooling system of the reactor pool was switched off in the experiments modelled and is thus not taken into account as a boundary condition.

Equations were solved using second order advection scheme and variable time step method was chosen in order to limit the number of iterations (less than 3 within each time step).

4 RESULTS AND DISCUSSION

In September 2012 a thermal power calibration was performed at Triga Reactor Centre at IJS. Time dependent power profile and temperatures profiles recorded at different positions (Figure 3) were provided by Reactor operation team. To sum up the experience, the reactor was started and operated during 280 minutes at a constant power level of 40kW before shutdown, in order to investigate the heat release through the concrete and into the atmosphere. To verify the computational model of the TRIGA pool, only the operation in the first few minutes after the shutdown was simulated.

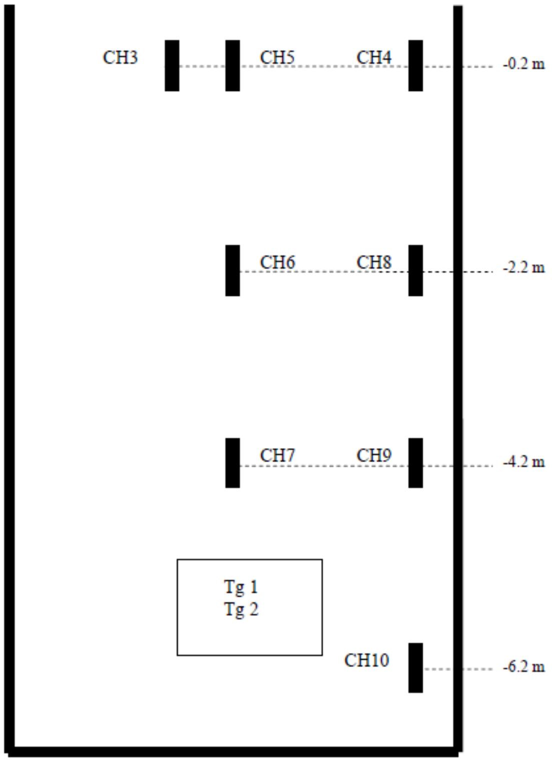

Figure 3: thermocouples positions in the Reactor

Visualisation of the results inside the core (TG1 and TG2 positions) is given only for 3 minutes following the start of the reactor and 2 minutes after the shutdown. During the operation temperatures of those 2 positions were almost constant. For the other thermocouples, only the time evolution during the operation makes sense since the beginning and the end of operation were too short to see any significant variation.

4.1 Temperatures in the core

During the first minutes following the start of the reactor, temperature in the core quickly rises before it reaching a constant value. Figure 4 presents the data collected from thermocouple and the data from calculation. One can see that the predicted temperature for the thermocouple 1 is in good agreement with experimental data while for the thermocouple 2 calculated temperatures are a slightly underestimated in the steady state.

During cooling down, both calculated profiles, shown in Figure 5 have a similar trend showing good agreement with experimental data.

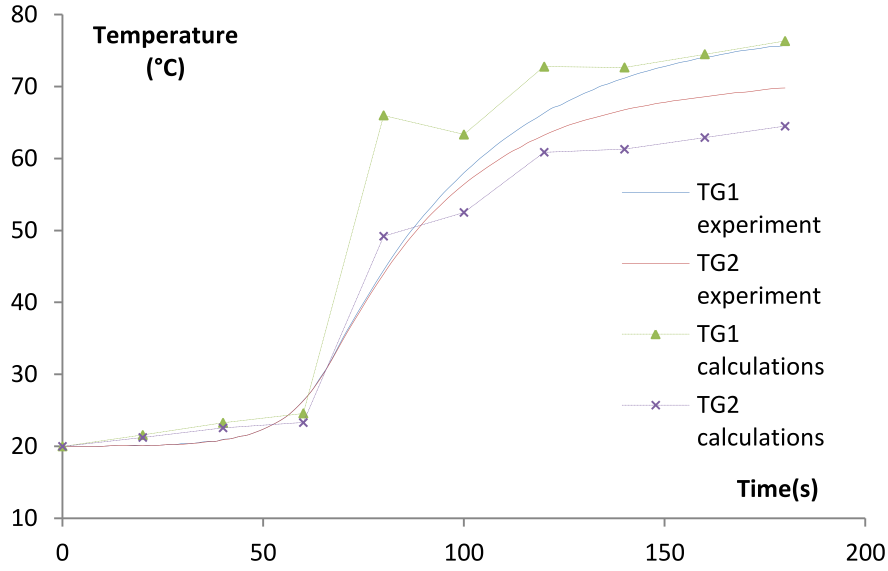

Figure 4: Time evolution of the water temperature in the core at the beginning

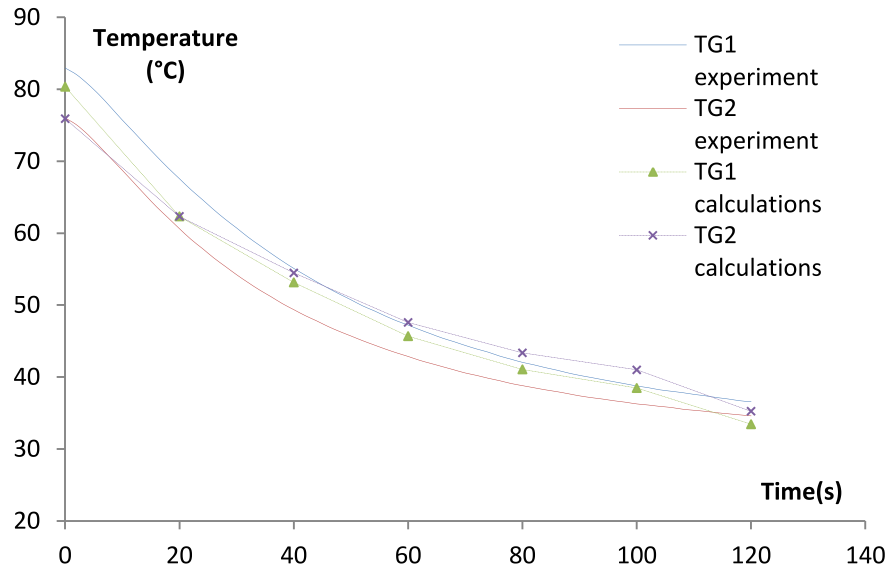

Figure 5: Time evolution of the water temperature in the core after shutdown.

This first verification indicates that the model is able to reproduce temperature profiles in the core location.

4.2 Temperatures in the pool

During the operation, the heat produced by the fuel will be released into the coolant resulting in a temperature growth in the pool. Experimentally, a 10°C increase was observed. As shown in Figure 6, this average behaviour was reproduced by our model. Nevertheless raise in our calculation is quicker at the beginning and slower at the end. This can be due to hypothesis made about thermal boundary conditions.

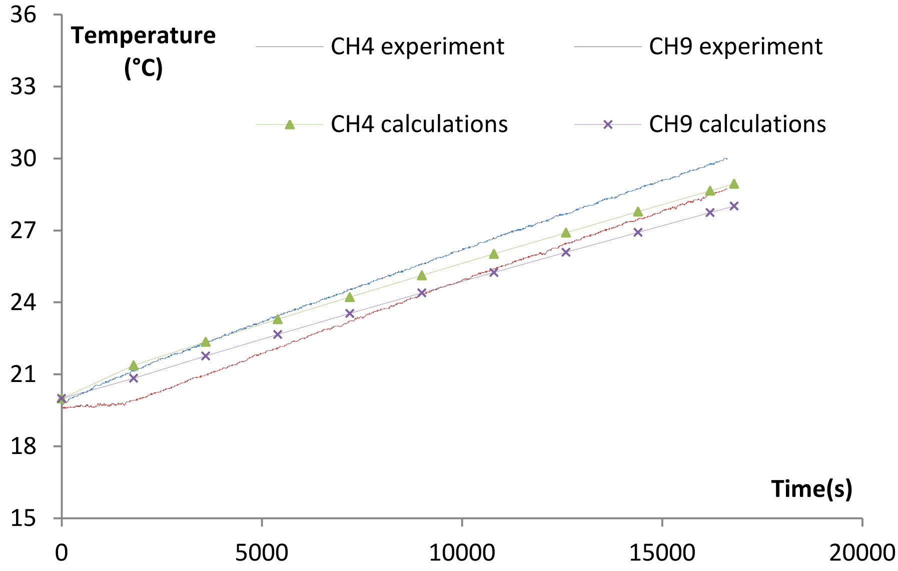

Figure 6: Time evolution of the water temperature in the pool.

From the results of the simulation, it is possible to identify natural convection behaviour of the flow. Figure 7 shows an increase of water temperature when moving up to the surface (following the line passing through CH5 and CH7), and a decrease of the temperature in the side of the pool when going down from the top (following the line passing through CH4 and CH9). Positions of the thermocouples can be seen in Figure 3. Experimental data do not show the same behaviour for the central channel. Measurement uncertainties might be an issue. However, the trends are similar since all the temperatures are measured in a narrow interval of ~3°C. Indeed the temperature difference (more than 0.5°C) between position 3 and 5 is questionable. On the side channel, trend for experimental data is the same as the difference in temperature already observed in Figure 6.

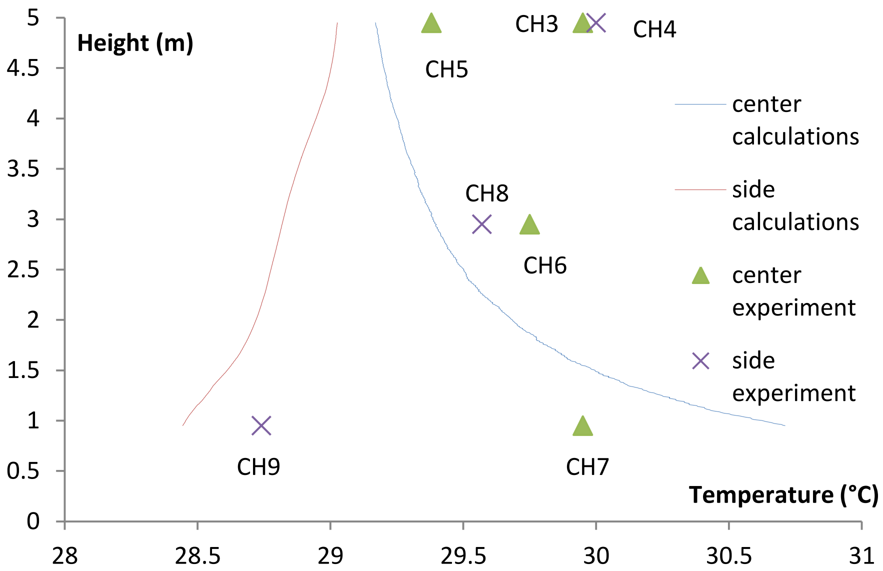

Figure 7: Natural convection evidence

Figure 8, shows a vector plot of velocities just before the reactor shutdown. Natural convection is clearly visible. There is no experimental data available for velocities so this plot should be taken with precaution whereas velocity values are in the known range for TRIGA reactor.

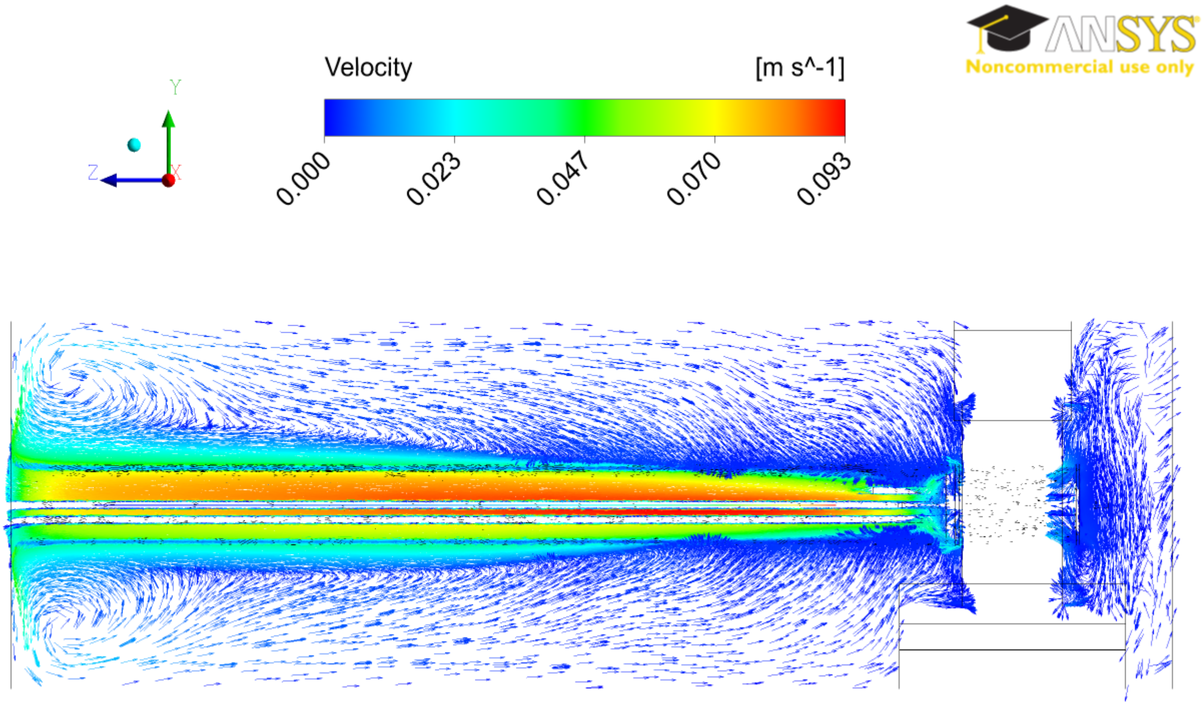

Figure 8: velocity vector field in the plan YZ

5 CONCLUSION

The first model of TRIGA reactor pool was created and was used to predict natural circulation in the pool with ANSYS CFX. Experiment performed in TRIGA reactor was reproduced for 3 transients (start of the reactor, constant power operation and shutdown of the reactor). Coolant temperature in the core reproduced the experimental data, especially during fast power variation. Furthermore, average coolant temperature, as expected, increased for 10°C during the constant power operation although the time evolution is slightly different. As the work is still in progress, future efforts will be devoted to improve boundary modelling, but also to estimate the measurement uncertainties.

Nevertheless, more accurate model will be needed to determine other physical quantities and to realise coupling with neutronic model of TRIGA reactor. Further experiments to determine complete flow parameters should also be performed.

ACKNOWLEDGMENTS

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