International Conference
**Nuclear Energy in Central Europe 2001**
**Hoteli Bernardin, Portorož, Slovenia, September 10-13, 2001**
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# INVESTIGATION OF SLIGHTLY FORCED BUOYANT FLOW IN A TRAINING REACTOR

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## ABSTRACT

A measurement based on the temperature noise analysis method was carried out in the Training Reactor of the Budapest University of Technology and Economics. The main goals were the estimation of the flow velocity immediately above the reactor core and investigation of the thermal-hydraulical conditions of the reactor, mainly in the core.

Subsequently 2D and 3D computations were carried out with the aid of the code CFX-4.3. The main objective of the 2D calculation was to clarify the thermal-hydraulical conditions of the whole reactor tank with a reasonable computing demand. It was also necessary to accomplish 3D numerical investigations of the reactor core and the space above since three dimensional effects of the flow could only be studied in this way. In addition, obtaining certain boundary conditions of the 3D computations was another significant aim of the 2D investigations.

It is important that the results of the noise analysis and the operational measuring system of the reactor gave us a basis for verifying our computations.

## 1 THE TRAINING REACTOR OF THE BUDAPEST UNIVERSITY OF TECHNOLOGY AND ECONOMICS

The training reactor of the Budapest University of Technology and Economics [1] is a tank type reactor with a maximum power of 100 kW, which is located on site of the university. The cylinder-shaped tank is 1.4 m in diameter and filled with desalted water. The coolant level is 5750 mm. The reactor core is made up of 24 fuel assemblies, which altogether contain 369 pieces of EK-10 type fuel rods with an active length of 500 mm. The fuel is 10% enriched uranium dioxide in magnesium matrix.

The reactor core is cooled by the buoyant flow of the coolant below 10 kW power. Over 10 kW the coolant loop is in process at a volumetric flow of 5.8 $m^3$/h.

## 2 THE MEASUREMENT AND THE MEASURING EQUIPMENT

Measurements were carried out in the Training Reactor with the goal being the investigation the flow velocity immediately above the reactor core. Pallagi stated that only the method of noise analysis could be used of measuring flow velocity in nuclear reactors cooled by buoyant flow [2]:

- There is excessively low pressure drop which can be experienced, moreover obstruction can not be built in a nuclear reactor.
- Moving equipment can not be applied in a nuclear reactor.

The equipment consists of 3 thermocouples of low heat capacity which were built in the appropriate holding structure and the signals were transported to a noise amplifier. The vertical distance was 5 mm and 10 mm between thermocouples 1 and 2 and between 2 and 3, respectively. The holder equipment was placed on two neighboring assemblies; the geometry and position are shown in Fig. 1.

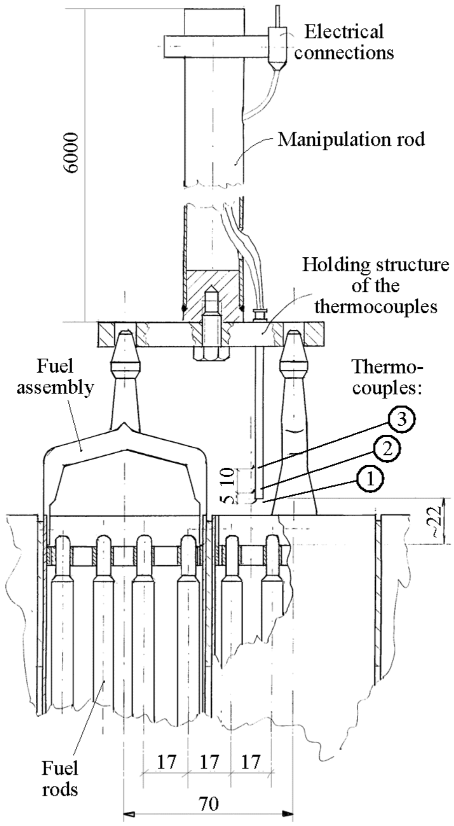


**Figure 1:** Structure and position of the measuring equipment at the top of the fuel assemblies

## 2.1 Results of the measurements

Typical coherence and phase function evaluated from the temperature fluctuations measured in thermocouple 1 and 2 can be seen in Fig. 2.

Noise analysis is a well-known method, which is widely used in reactors [3], to estimate transit time of the coolant between the thermocouples using the phase and/or cross correlation between the signals of the thermocouples. There is linear phase dependence which can be seen in Fig. 2 in the 0 to 6 Hz interval with considerable coherence. The transit time between thermocouples can be stated from the tangent of the phase – frequency function.

Briefly summarizing the results the following can be stated:

- Velocity values measured between thermocouples 1 and 2 are approximately two times greater than the measured value between thermocouples 2 and 3.
- 4 to 7 cm/s were typical velocity values measured between thermocouples 1 and 2.
- 2.5 to 4 cm/s were typical velocity values measured between thermocouples 2 and 3.

Due to the difficulties which arouse during the measurements the results could only be obtained with large variations. Therefore the analysis of the results and extended measurements based on the lessons learned from the calculations described in the following chapters are in progress.

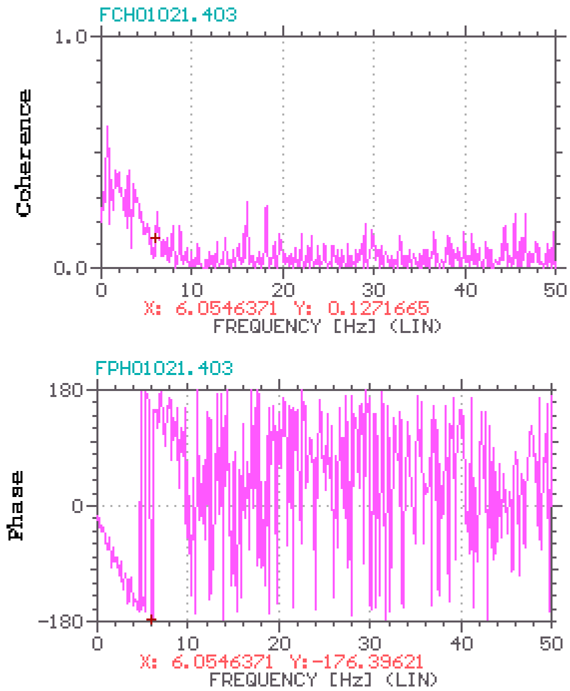


**Figure 2:** Coherence and phase function based on result of measurement carried out 135 minutes after start-up

## 3 CFD COMPUTATIONS WITH THE CFX CODE

The main goal of the CFD (Computational Fluid Dynamics) computations was to examine the thermal-hydraulic conditions of the Training Reactor and to compare the results with the measurements.

Since the reactor tank is cylindrical, it is obviously useful to transform the geometry into equivalent cylinders, thus obtaining a reasonable computational demand for whole-tank investigations.

In addition it was necessary to accomplish 3D numerical investigations of the reactor core and the space above since three dimensional effects of the flow could only be studied in this way.

### 3.1 Determining boundary conditions for the 3D CFX computations

Since the coolant warms up in the boundary layers of the fuel rods, significant temperature differences develop in the coolant water. It leads to the development of hot water plumes. Therefore it is indispensable to carry out 3D investigations of the cooling channels. In order to accomplish these computations, first it is essential to determine certain boundary conditions:

- The inlet average flow velocity at the bottom of the fuel rods.
- The average coolant temperature at the bottom of the fuel rods.

These conditions were in turn determined by 2D CFX computations.

# 4 2D COMPUTATIONS WITH THE CFX CODE

## 4.1 The geometry model applied

The 2D model was set up by transforming the geometry into cylinders of volume identical to the original objects.

The reactor tank was defined as a 5750 mm high cylinder with a diameter of 1400 mm. The reactor cylinder was positioned coaxial to the tank. The reflector is not part of the thermal-hydraulical processes so the equivalent cylinder is defined as an out-of-simulation region. The other structure elements were not modeled.

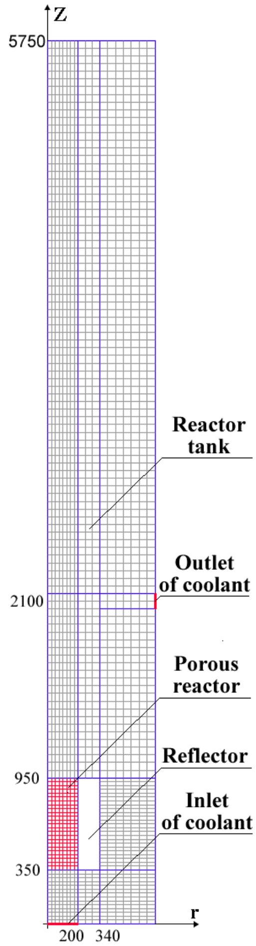


**Figure 3:** Geometry model for 2D computations

## 4.2 Boundary conditions of the 2D computations

The coolant enters at the bottom of the tank. Because of the injectors and diffuser it enters the core with approximately uniform velocity. Therefore the coolant was modeled as an inlet boundary condition with an area equivalent to the reactor core cross-section. The normal velocity of the inlet was set to

$$v_{in} = \frac{\dot{V}}{A_C} = 1.28 \text{ cm/s} \tag{1}$$

where $\dot{V}$ =5.8 $m^3/h$ and $A_C$ is the cross-section of the inlet in the model.

### 4.3 The homogeneous reactor model

The reactor core was modeled as a porous region with porosity of 0.74. First the heat power density was set uniform with a value of $\dot{Q}'''$=1.326 MW/m$^3$.

### 4.4 Other settings of the model

Numerical and physical parameters set to the model are:

- Flow type: natural buoyant flow.
- Turbulence model: low Reynolds-number K-epsilon [4].
- Fluid model: incompressible.
- Mass source tolerance: 0.001 kg/s in the first minutes, later decreased to about 0.0001 kg/s.

### 4.5 Solutions of the 2D computations performed with the homogeneous reactor model

According to the calculations approximately 3 hours after start-up the characteristics of the temperature and velocity fields do not change significantly (Fig. 4).

The calculations show that there is not significant circulation around the reflector, so the coolant, which enters through the inlet, gets directly to the reactor core. This result is of great importance since the missing boundary conditions for the 3D computations became available.

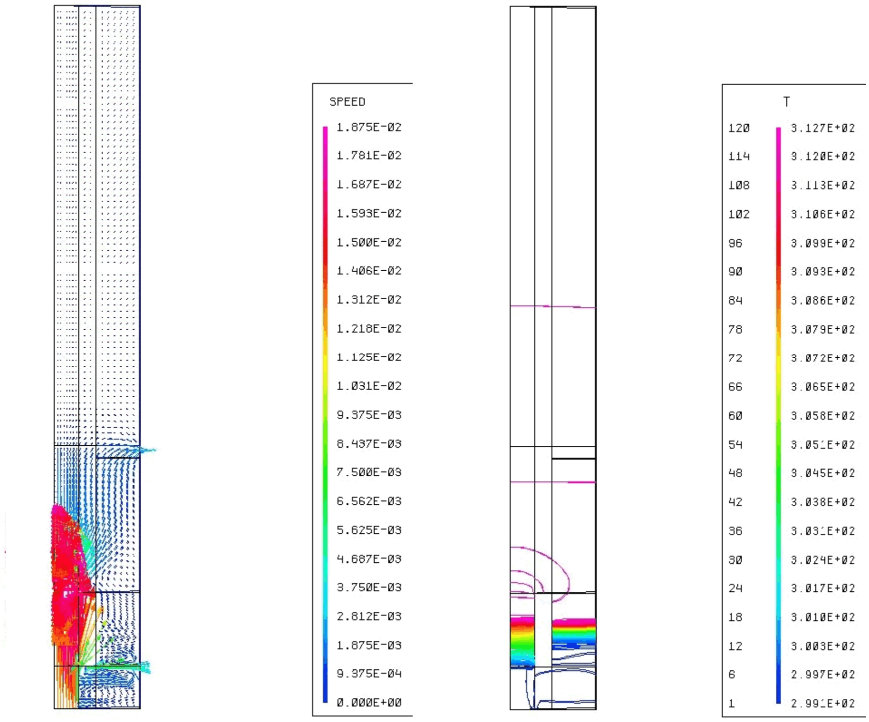


**Figure 4:** Velocity and temperature field 3 hours after start-up

According to the computational results, the upper part of the tank forms an approximately uniform temperature block. However, measurements show some circulation and temperature stratification in the upper part of the tank. The disagreement can be explained with the existence of the hot water plumes. Since the first model contained a uniform volumetric heat source in the reactor, the phenomenon of hot water plumes could not appear in these calculations. A new model was defined for handling this phenomenon.

## 4.6 The inhomogeneous reactor model

The word "inhomogeneous" refers to the fact that the heat source density is set non-uniformly in this model. In the central region the heat source value is defined 60% higher than in the external region. This model is intended for an experiment, i.e. the model was used to test whether it is capable of reproducing the phenomena of the hot water plumes. The results mostly satisfied our qualitative expectations (Fig. 5):

- The circulation was found to stay significant in the upper part of the tank even in the 4th hour of the transient.
- The temperature stratification could also be experienced, but found to be much less significant than measured before.
- The computed outlet temperature data were in good agreement with the measured ones (Tab. 1).

| Time [h] | $T_{in}$ | $T_{out}$ | $T_3$ * | $T_4$ ** | $T_{out, computed}$ | $T_{3, computed}$ * |
|---|---|---|---|---|---|---|
| 0 | – | – | 30 | 27 | 27 | 27 |
| 0,5 | 23 | 31 | 36 | 33 | 31,3 | 30,5 |
| 1,5 | 25 | 37 | 42 | 39 | 36,2 | 36,8 |
| 2,5 | 26,5 | 41 | 46 | 44 | 39,8 | 40,2 |
| 3,5 | 28 | 44 | 50 | 46 | 42,2 | 42,6 |
| 4,5 | 28,5 | 45,5 | 51,5 | 46 | *** | |
| 5,5 | 29 | 46 | 52 | 47 | | |
| 6,5 | 29 | 46 | 52,5 | 48 | | |

**Table 1:** Measured and computed temperature data in the reactor and its cooling circuit
* Thermocouple 3 positioned 1 meter under the water level
** Thermocouple 4 positioned immediately above the reactor core
*** The experiment took 4 hours so further computations were not accomplished

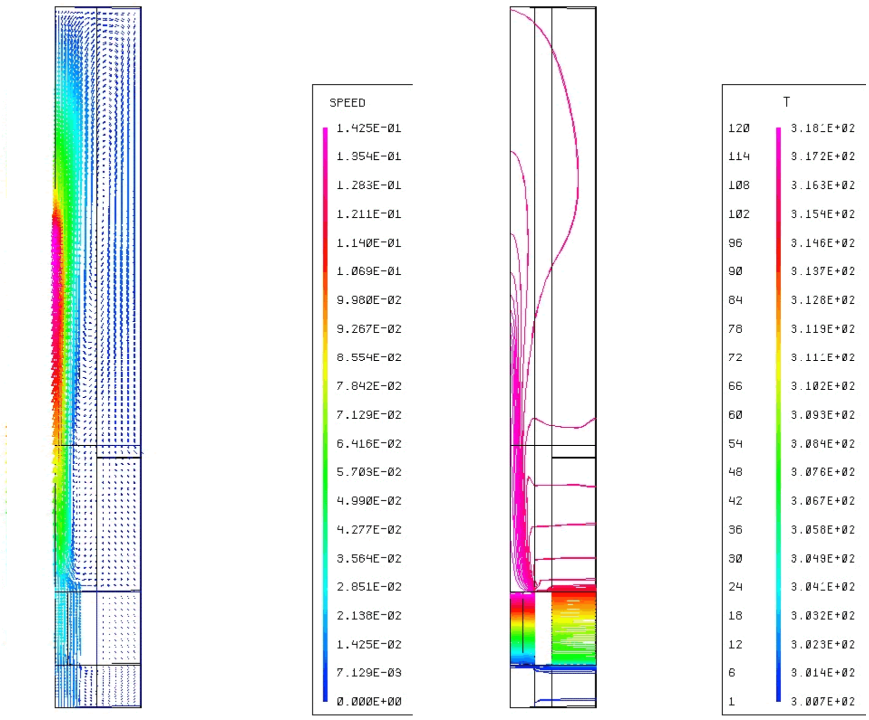


**Figure 5:** Velocity and temperature field 4 hours after start-up

## 4.7 Conclusions on the 2D computations with the inhomogeneous model

The computations discussed above show that the 2D computations could not be continued without carrying out 3D calculations:

The results for the upper part of the reactor tank are not acceptable without modeling the phenomenon of the development of hot water plumes.

The phenomenon of hot water plumes can only be modeled with 3D calculations.

It is expected that the parameters of the inhomogeneous reactor model can be set so that handling of the phenomenon of hot water plumes in 2D calculations will be available.

# 5 3D COMPUTATIONS WITH CFX

The results of the measurements discussed before can only be compared to the results of the 3D calculations. Typical results can be seen in Fig. 6. These calculations were carried out for the elementary cooling channel, which is made up of a 500 mm high active and 34.5 mm high inactive part of a fuel rod and a 50 mm high water column above it.

It can be seen that the velocity depends very heavily on the radial co-ordinates of the position. It was stated before that there are significant differences between the velocity values measured between thermocouples 1 and 2 and thermocouples 2 and 3. The fact that the plumes are not perfectly vertical can explain this phenomenon. Also, in accordance with the measurements the calculations show that the plumes are very thin and high velocity values of maximum 6.7 cm/s can be reached. This explains also big variations in the measured velocities.

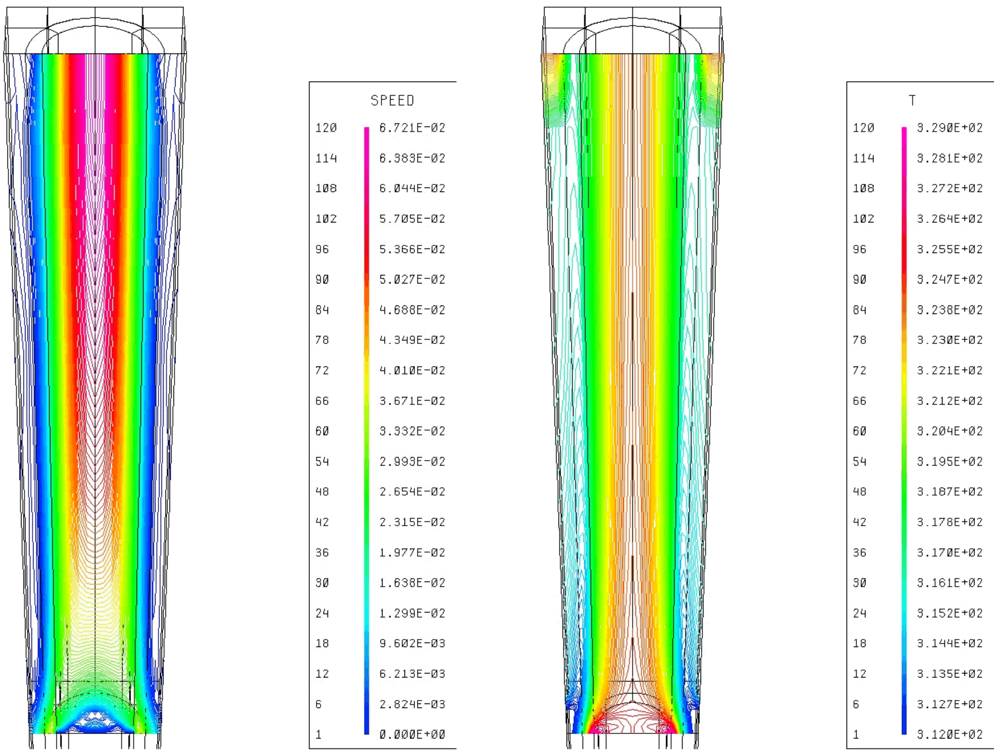


**Figure 6:** Velocity and temperature field above a fuel element

In spite of the above mentioned, concerning the measured data one has to take into account the following:

- Measurements were only performed in one position.
- The positioning of the equipment bore uncertainties.

## 6 FURTHER WORK IN THE NEAR FUTURE

The following activity are planned or already in process:

- 3D calculations on fuel rod groups for investigating the interaction between the plumes developing immediately above the fuel rods.
- Continuation of 2D calculations with the improved inhomogeneous reactor model.
- Extension of the measurements. More data are needed from different position of the measuring equipment.

## SUMMARY

A measurement based on the temperature noise analysis method was carried out in the Training Reactor of the Budapest University of Technology and Economics.

Subsequently 2D and 3D computations were performed with the aid of the code CFX-4.3. The main objective of the calculation was to investigate the thermal-hydraulical conditions of the whole reactor tank. In addition, obtaining certain boundary conditions of the 3D computations was another significant aim of the 2D investigations.

The main result of the 2D computations was that there is no significant circulation around the reflector. It means that the coolant entering through the inlet gets directly into the reactor core.

The 2D results did not show the phenomenon of the hot water plume above the reactor. Therefore a new, so-called inhomogeneous reactor model was defined. The computations completed with the inhomogeneous model showed the phenomenon of the hot water plume.

3D calculations performed for modeling the phenomenon of hot water plumes developing immediately above the fuel rods. The results of the 3D calculations were in a good agreement with the results of the measurement. In addition, it is expected that the parameters of the 2D model can be set so that it will be capable to model slightly forced buoyant flows with the aid of these calculations.

## REFERENCES

[1] Technical documentation of the Training Reactor of the Budapest University of Technology and Economics

[2] D. Pallagi, *Measuring the velocity of NPP coolants with correlation method*, PhD thesis, KFKI Atomic Energy Research Institute, Budapest, 1978

[3] A.J.C. Stekelenburg, T.H.J.J. van der Hagen, “Experience with the Application of noise analysis”, Proc. SMORN-7, Avignon, France, 1995, vol.1, pp. 474,

[4] E. Krepper, F.-P. Weiss and H.-G. Willschuetz, “Finite volume and finite element calculations to the 7-th IAHR-benchmark-test”, ICONE-7, Tokyo, Japan, April 19-23, 1999, to be published