2017 International Nuclear Atlantic Conference - INAC 2017
Belo Horizonte, MG, Brazil, October 22-27, 2017
ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR – ABEN

Agência Brasileira do ISBN
ISBN 978-85-99141-07-6

EXPERIMENTAL INVESTIGATION OF CRITICAL VELOCITY IN A PARALLEL PLATE RESEARCH REACTOR FUEL ASSEMBLY

Alfredo J. A. Castro, Nikolas L. Scuro and Delvonei A. Andrade

Instituto de Pesquisas Energéticas e Nucleares (IPEN / CNEN - SP)
Av. Professor Lineu Prestes 2242
05508-000 São Paulo, SP
ajcastro@ipen.br

ABSTRACT

The fuel elements of a MTR (Material Testing Reactor) type nuclear reactor are mostly composed of aluminum-coated fuel plates containing the core of uranium silica (U_3Si_2) dispersed in an aluminum matrix. These plates have a thickness of the order of millimeters and are much longer in relation to their thickness. They are arranged in parallel in the assembly of the fuel element to form channels between them a few millimeters in thickness, through which there is a flow of the coolant. This configuration, combined with the need for a flow at high flow rates to ensure the cooling of the fuel element in operation, may create problems of mechanical failure of fuel plate due to the vibration induced by the flow in the channels. In the case of critical velocity excessive permanent deflections of the plates can cause blockage of the flow channel in the reactor core and lead to overheating in the plates. For this study an experimental bench capable of high volume flows and a test section that simulates a plate-like fuel element with three cooling channels were developed. The dimensions of the test section were based on the dimensions of the Fuel Element of the Brazilian Multipurpose Reactor (RMB), whose project is being coordinated by the National Commission of Nuclear Energy (CNEN). The experiments performed attained the objective of reaching Miller's critical velocity condition. The critical velocity was reached with 14.5 m/s leading to the consequent plastic deformation of the flow channel plates.

1. INTRODUCTION

The fuel elements of a MTR (Material Testing Reactor) type nuclear reactor are mostly composed of aluminum-coated fuel plates containing the core of uranium silica (U_3Si_2) dispersed in an aluminum matrix. These plates have a thickness of the order of millimeters and are much longer in relation to their thickness. They are arranged in parallel in the assembly to form few millimeters thick channels, through which the cooling fluid flows, Figure 1, Torres et al [1].

This configuration coupled with the need of high flow rates to ensure the cooling of the plates in operation, can generate problems of mechanical failure of the fuel plates due to the vibrations induced by the flow in the channels and, consequently, accidents of serious proportions. Miller [2], one of the pioneers of fuel plate stability research, describes the collapse of the plates as due to the difference in velocities between adjacent channels. This difference in velocity produces a pressure difference between both sides of a plate. When the resulting pressure is large enough for the plate to withstand, maximum deflection and plastic deformation occur. Critical velocity is the speed at which the rectangular plates will deflect and collapse as a result of flow induced vibrations and the asymmetric distribution of pressures within the fuel element. This deflections on the sides of the plates can cause blockage of the flow in the reactor core and lead to overheating in the plates.

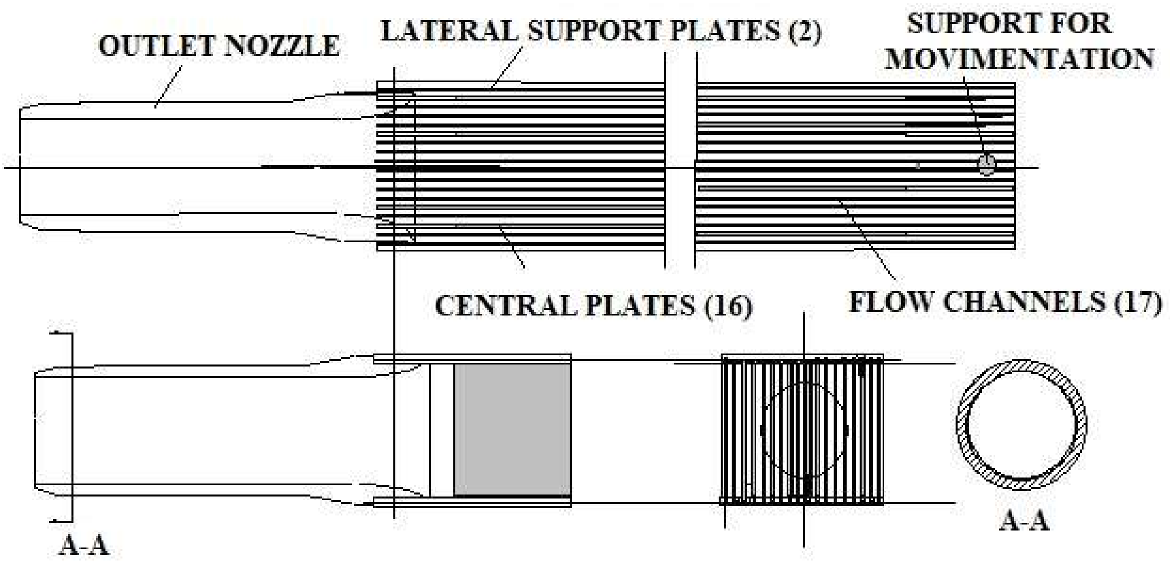

Figure 1- Assembly of a fuel element of flat plates.

2. EXPERIMENTAL PROCEDURE

For the study of the plates collapse and critical velocity detection it was decided by a test section model that simulated the fuel element with the basic dimensional characteristics of the design of the Brazilian Multipurpose Reactor, Silva [3].

The test section model consists of two aluminum plates, six aluminum spacers and two acrylic plates mounted on a sandwich structure that divides the rectangular flow section into three identical coolant channels. The test section has the dimensions of 850 mm x 100.5 mm x 30.5 mm. The model of the fuel element has one of the aluminum plates instrumented with extensometers of 350 Ohm in three positions: inlet (SG1, SG2), center (SG3, SG4) and outlet (SG5, SG6) of the cooling channels. In Figure 2, the sandwich structure, a cross section and a photo of the test section are shown.

The static pressure measurement serves as a secondary method for the detection of plate collapse. The static pressure measurement in the cooling channel was measured with four piezoresistive microsensors installed on the external acrylic plate to the flow channel. For the investigation of critical velocity in fuel elements, a new experimental test bench was developed and assembled at the Nuclear Engineering Center (CEN), Figure 3.

The average velocity in the test section was increased by acting on the main globe valve (VG1). The signals from the process and strain sensors in steady state condition were monitored and recorded.

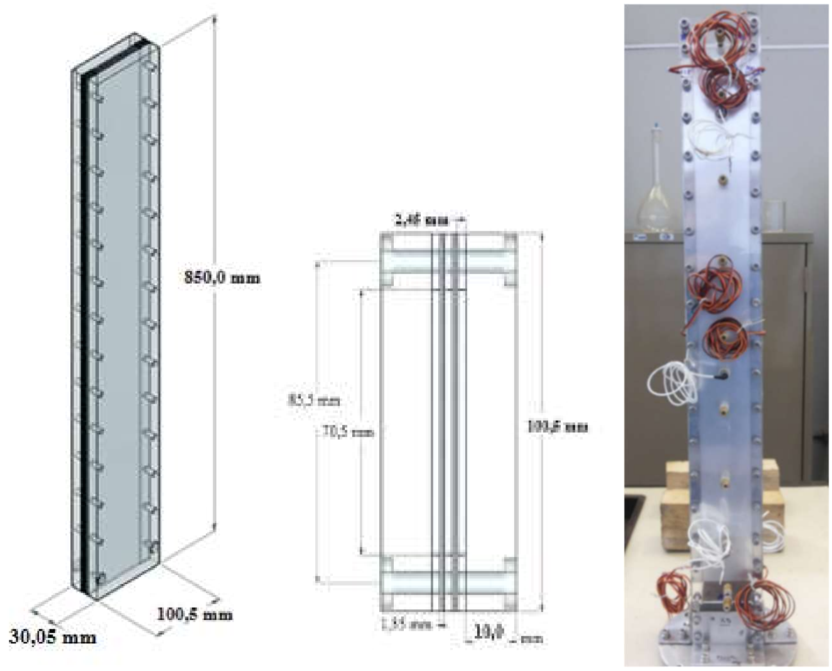

Figure 2 - Model of the fuel element type flat plates.

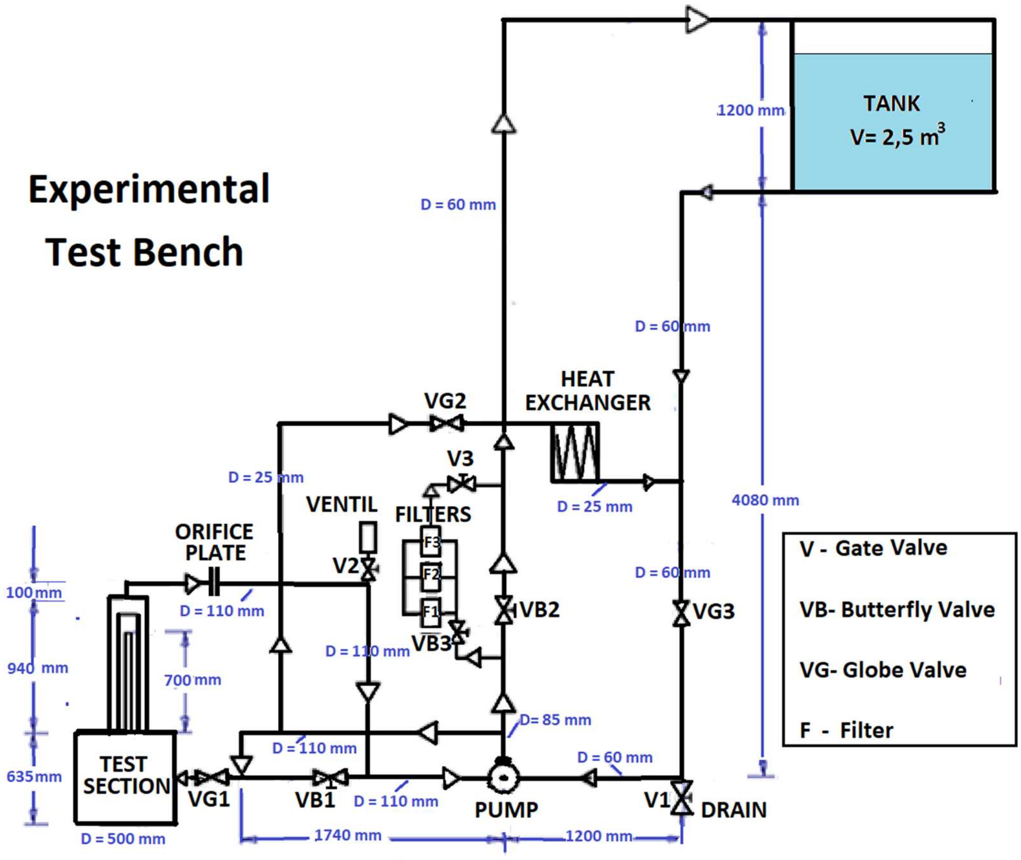

Figure 3: Experimental Test Bench.

3. RESULTS AND DISCUSSION

Figure 4 shows the pressure drop curve between the inlet and outlet in the test section, ΔP, against channel mean velocity. In this curve, it can be observed that during the experiments there was a linear tendency of increase of ΔP. From the velocity 14.0 m/s there was a decrease in the hydraulic resistance of the test section, which is a consequence of the collapse of the plates due to the plastic deformations in the flow channels.

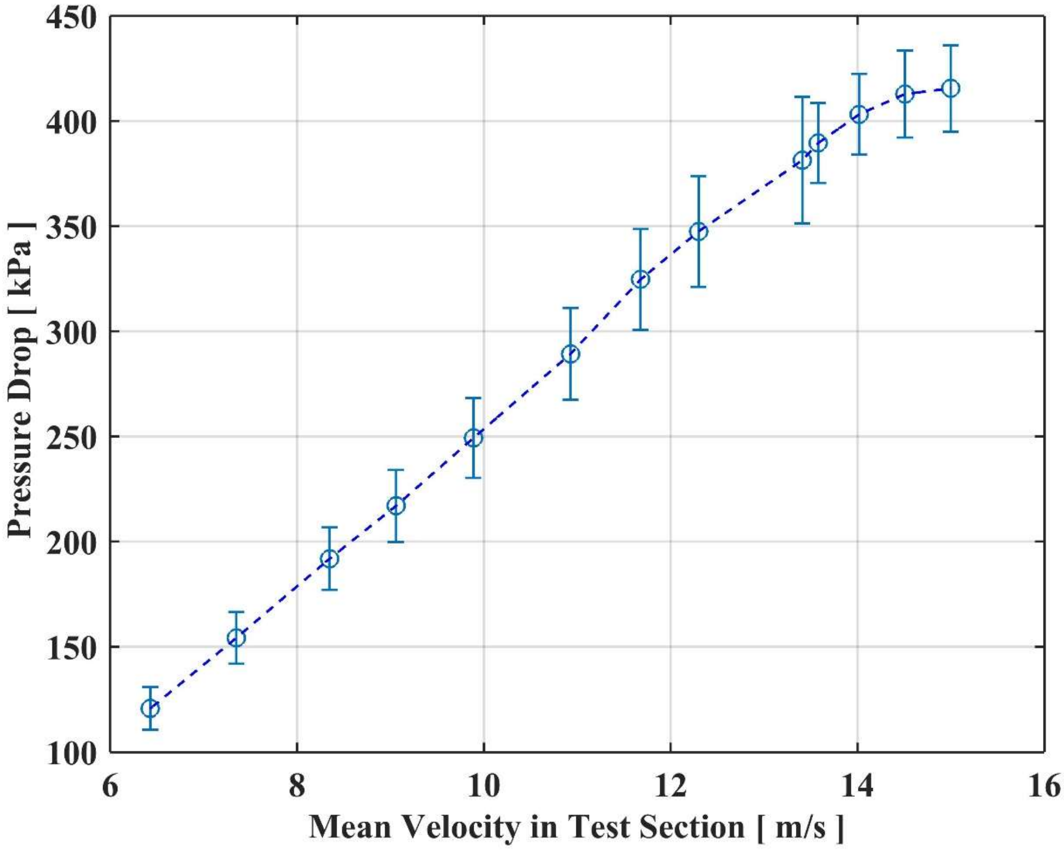

Figure 4: Pressure Drop in the Test Section.

In the experiments, it can be observed that the signals of the extensometers showed a behavior of increase of deformations with the average velocity of the test section of a continuous and gradual way. It was observed the higher deformations in the middle of the test section (SG3) and lower in the output (SG6). From 14.0m/s, the increase of deformations by velocity gain has jumped. This can be observed mainly when the velocity varied from 14.0 to 14.5 m/s, Figures 5 and 6. It is assumed that this was the starting point for the plates collapse and the beginning of the plastic deformation.

Figure 7 shows a picture of the channels of the test section inlet after the critical velocity experiments. The deformation of the central channel is clearly seen blocking the lateral channels.

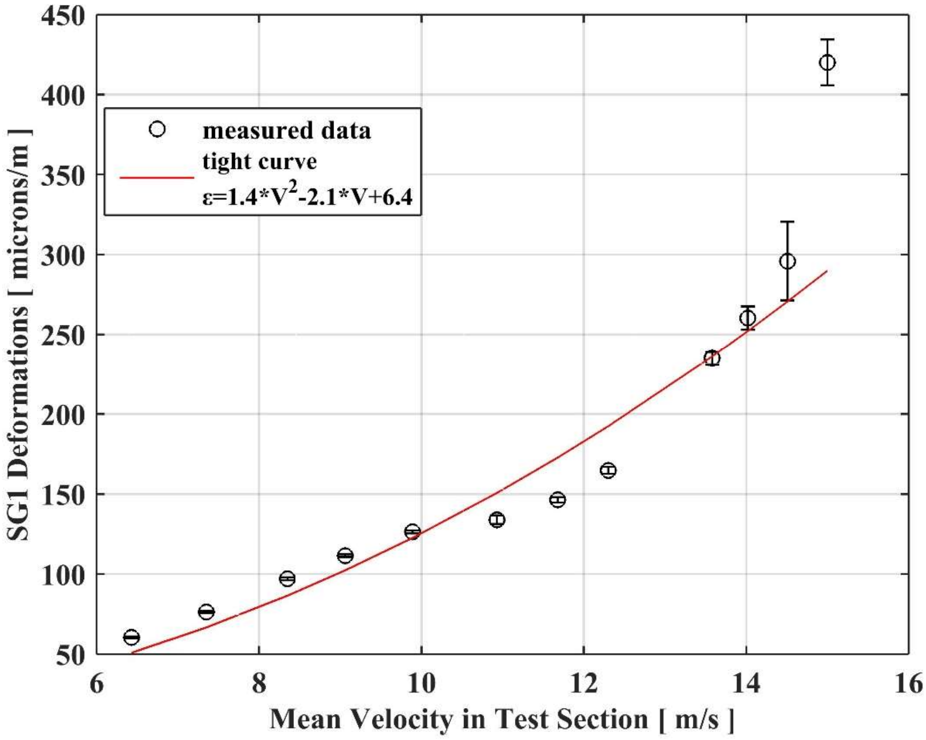

Figure 5: Deformations in the inlet (SG1) of the test section.

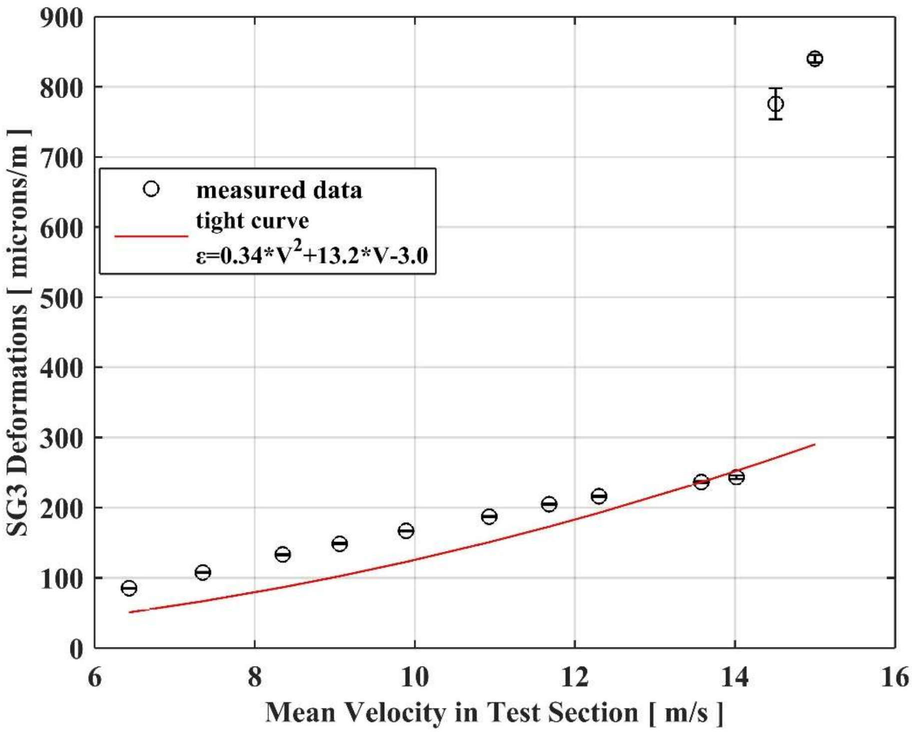

Figure 6: Deformations in the middle (SG3) of the test section.

Figure 7: Test Section after Critical Velocity Experiment.

In the frequency field analysis, a probable component of elastic fluid instability was not observed in the signals of the strain gauges in conditions close to the occurrence of the critical velocity. Figure 8 shows the power spectral density of the extensometer of the middle of the test section (SG3) for different mean velocities in the channel. A fluid-bound excitation (broadband) was observed with its value increasing from 90 to 130 Hz with the velocity growth in the channel. This excitation is probably linked to cavitation in the middle of the channel of the test section. The deformation at the center of the channel was much larger than that at the inlet, causing great resistance to flow, high fluid velocities and very low pressures. In this graph resonances in the region of 300 to 500 Hz are also observed. These resonances are results of plate vibrations and fluid vortices of turbulences. These turbulence vortices are most likely produced at the exit of the test section. The plenum chamber of the test section (Plenum) reduces possible influences of fluid phenomena in the hydraulic circuit such as fluid resonances, cavitation in the flow control valve and pump pressure pulses.

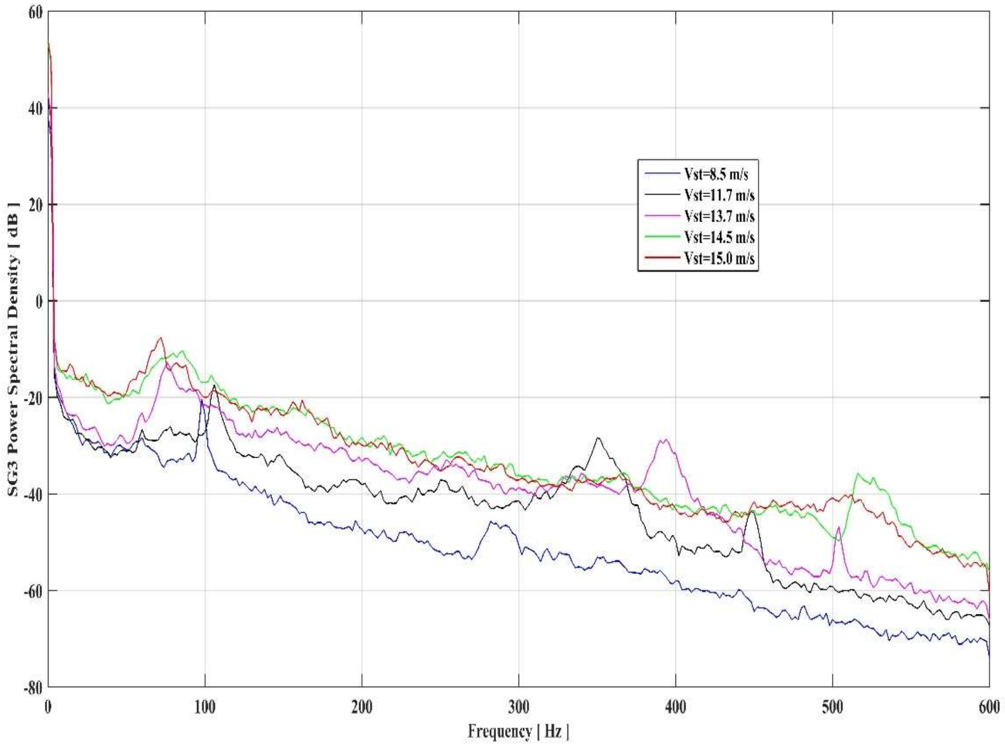

Figure 8: Power Spectral Density SG3.

3. CONCLUSIONS

The experiments performed reached Miller's critical velocity condition. There was collapse and consequent plastic deformation of the plates forming the flow channel with the average velocity of the test section of 14.5 m/s. The collapse of the plates occurred with the velocity equivalent to 85.5% of the value calculated by the Miller equation that was 17.0 m/s. This result is compatible with the experiments of Ho et al. [4].

The signals of the strain gauges showed a behavior of the plate deformations, proportional to the squared velocity up to 14.0 m/s, in accordance with the hypotheses of the Miller model [2], which uses the Euler-Bernoulli equation applied to the wide beam theory. It was observed that at velocities up 14.0 m/s the deformations presented behaviors proportional to the high velocities at higher degree powers. This fact was used to characterize the occurrence of plates collapse and occurrence of the critical velocity at 14.5 m/s. This technique of plate collapse characterization is unique for critical velocity detection experiments.

The occurrence of critical velocity was observed visually during the disassembly of the test section, illustrated and discussed in the results analysis presented in this work. Blockage of the channels was also observed by means of the pressure drop plot against the mean velocity of the test section. There was a drop in the hydraulic resistance of the test section due to the increase of the cross-section of flow in the central channel.

ACKNOWLEDGMENTS

The authors are grateful for the support of the technician Murilo Santos, students and the fellow researchers who collaborated with the development of the research project and experimental investigation. The authors gratefully acknowledge the support by CNPq, process number 481193/2012-0, and IPEN for providing a research grant for this scientific research.

REFERENCES

1. W.M. Torres, P.E. Umbehaum, D.A. Andrade, D., J. Souza., “A MTR fuel element flow distribution measurement preliminary results,” *Proceedings of 2003 International Meeting on Reduced Enrichment for Research and Test Reactors*, Chicago, 2003, 6 p
2. D. Miller, “Critical flow velocities for collapse of reactor parallel-plate fuel assemblies,” *Knolls Atomic Power Laboratory Report, United States Atomic Energy Commission contract n° W-31-109 Eng-52*, New York, 1958.
3. J.E.R. Silva, “Descrição do projeto de concepção do núcleo, componentes, estruturas e instalações associadas ao núcleo do Reator Multipropósito Brasileiro- RMB,” *IPEN* , Brazil, 08/2013.
4. M. Ho, G. Hong, A.N.F. Mack, “Experimental investigation of flow-induced vibration in a parallel plate reactor fuel assembly,” *15th Australian Fluid Mechanics Conference*, The University of Sydney, Sydney, 4 p, 2004.