2013 International Nuclear Atlantic Conference - INAC 2013
Recife, PE, Brazil, November 24-29, 2013
ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR - ABEN
ISBN: **978-85-99141-05-2**

Test Section for Experimental Simulation of Loss of Coolant Accident in an Instrumented Fuel Assembly Irradiated in the IEA-R1 Reactor

Eduardo Maprelian[1], Walmir M. Torres[2], Pedro E. Umbehaun[3], Antonio T e Silva[4] and Gaianê Sabundjian[5]

Instituto de Pesquisas Energéticas e Nucleares (IPEN / CNEN - SP)
Av. Professor Lineu Prestes 2242
05508-000 São Paulo, SP
[1]emaprel@ipen.br
[2]wmtorres@ipen.br
[3]umbehaun@ipen.br
[4]teixeira@ipen.br
[5]gdjian@ipen.br

ABSTRACT

Loss of Coolant Accident (LOCA) in pool type Research Reactors, are related to partial or complete loss of pool water, with consequent partial or complete uncovering of the fuel assemblies. For the safety of the facility, the core uncovering must be prevented to the maximum. This paper presents the development of a test section (STAR) for the simulation of Loss of Coolant Accidents (LOCA) in Research Reactors. The test section aims to conduct, in a controlled and safe way, partial and total loss of coolant experiments in an Instrumented Fuel Assembly (IFA) irradiated in the core of the IEA-R1 reactor of IPEN-CNEN/SP, and obtain data to comparison with computer codes for LOCA analysis in Research Reactors. The comparison will serve as a future qualification of calculation programs. STAR comprises a base on which is fixed the IFA, the cylindrical stainless steel hull, the compressed air system for the section emptying and refilling and the instrumentation. Shall be measured the water level in the section and the temperatures of the IFA, the air inside the section and pool water near the section.

1. INTRODUCTION

In pool type Research Reactors (RR), like IEA- R1 and RMB (Brazilian Multipurpose Reactor), the reactor core is submerged into a pool of water, which among other functions, must ensure the removal of its decay heat from the same (safety function). In general, this heat removal is done passively by natural circulation of water, without dependence on external sources of energy, for a time longer than necessary to maintain the physical integrity of the fuel assemblies and the containment of radioactive material (safety function).

The Loss of Coolant Accident (LOCA) is considered as the most severe, accident for the pool type RR [1]. The LOCA in this type of reactor are related to the partial or total loss of pool water, with the consequent partial or total fuel assemblies uncovering.

A complete LOCA in reactor power plants can result in partial melting of the fuel from decay heat and release of fission products into the reactor building. For reactors operating even at relatively low power, the consequences of a complete LOCA must be examined [2].

It should be emphasized the importance of a LOCA with partial core uncovering to a level below its active length. In this accident, in addition to the loss of the cooling water, there is also the obstruction of the nozzle of the fuel assembly by the pool water and in this situation the cooling by natural circulation of the air through the fuel assemblies is not possible. In this accident there is no contribution of convection and evaporation of water present in a partial LOCA above of the active length. In this way, this blockage of air flow can represent a more critical condition than the total core discovery [3 and 4].

For the analysis of loss of coolant accident, it is necessary the application of calculation tools suitable for each particular condition. For a proper use of these computational tools, it is recommended to consider experimental data and to perform code to-experiment comparison before any code application to prediction relevant to the RR design or safety analysis [5 and 6]. Few experimental works on loss of coolant accidents RR have been published in the open literature, having thus a small availability results for analysis and comparison with calculation programs, particularly to the partial uncovering condition.

One of the world's latest LOCA experiments in MTR type fuel assemblies was published in 1998 and refers to the 5 MW TR-2 Turkish Research Reactor [7 and 8]. Three LOCA experiments, with different cooling times, were performed using an instrumented fuel assembly with 5 thermocouples. After to be removed from the core, the instrumented fuel assembly was placed in a container shielded with lead into the pool. Then, the container with the instrumented assembly was removed from the pool and placed in contact with air behind a concrete shielding wall. In this experiment has not been verified the partial uncovering of the assembly or the blockage of the natural circulation air by the water in the assembly nozzle.

The objective of this paper is to present the project of the Test Section for Analysis of Loss of Coolant (STAR). The STAR was designed to conduct experiments of partial and complete loss of coolant, using an Instrumented Fuel Assembly (IFA). The proposed experiments aim the reproduction of heat transfer conditions similar to those expected in loss of coolant accident (LOCA) in RR, in a safe and controlled way. Experimental data can be used to validation or development of computational tools for LOCA analysis.

2. TEST SECTION FOR ANALYSIS OF LOSS OF COOLANT (STAR)

The Test Section for Analysis of Loss of Coolant (STAR) was designed to simulate loss of coolant experiments using the Instrumented Fuel Assembly (IFA) EC-208 of the IEA-R1 Research Reactor [9].

The IFA was developed by IPEN researchers to operate in the IEA -R1 [2]. The IFA is identical to a standard fuel assembly of U_3Si_2-Al with a density of 3,0 gU/cm^3, where fourteen thermocouples distributed as follow:

- Coolant inlet and outlet temperature,
- Three channels, one central and two lateral channels, each is equipped with 3 thermocouples for the clad and 1 for the fluid temperatures.

STAR seeks to reproduce heat transfer conditions similar to those expected in LOCA. Two types of LOCA are possible to simulate by STAR, the total and the partial uncovering of the fuel assembly.

STAR comprises a base, the cylindrical stainless steel hull, the compressed air system and the instrumentation. Figs. 1 e 2 shows a schematic representation of the STAR.

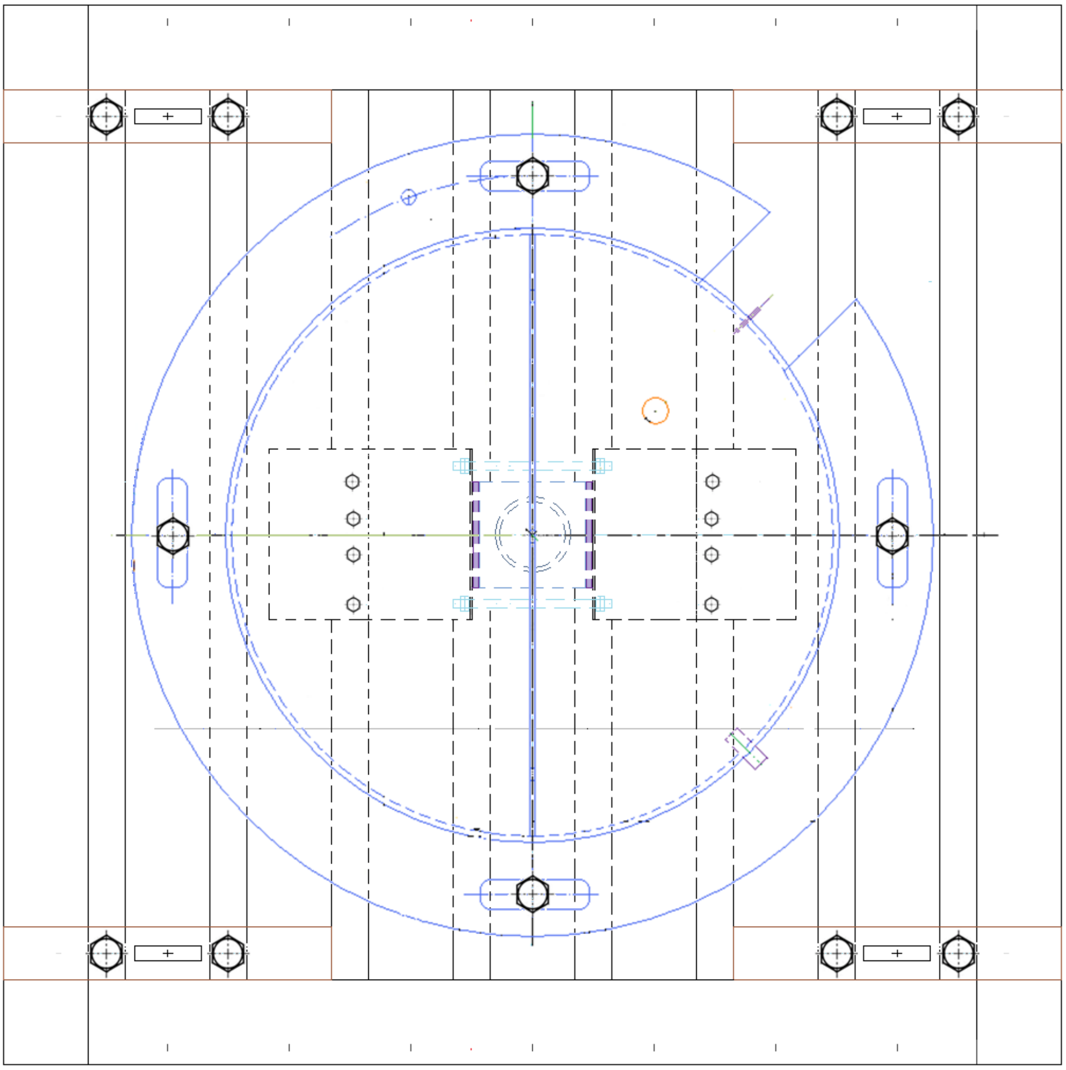

Figure 1: Schematic Representation of the STAR - Plant.

2.1. Base

The base of the STAR is composed of two aluminum pallets, stainless steel supports, plates and screws, the lead (and steel) counterweight, the aluminum box and the aluminum nozzle. The aluminum nozzle is for the positioning of the IFA and the simulation of a matrix plate. The nozzle is attached at the base by brackets, screws and plates of stainless steel. On the faces of the nozzle supports are placed thermal insulation to minimize heat exchange by conduction to the base structures. An aluminum box covers the lead counterweight avoiding its contact with the water. The base has four lifting eyes positioned in their corners for the transport of the section.

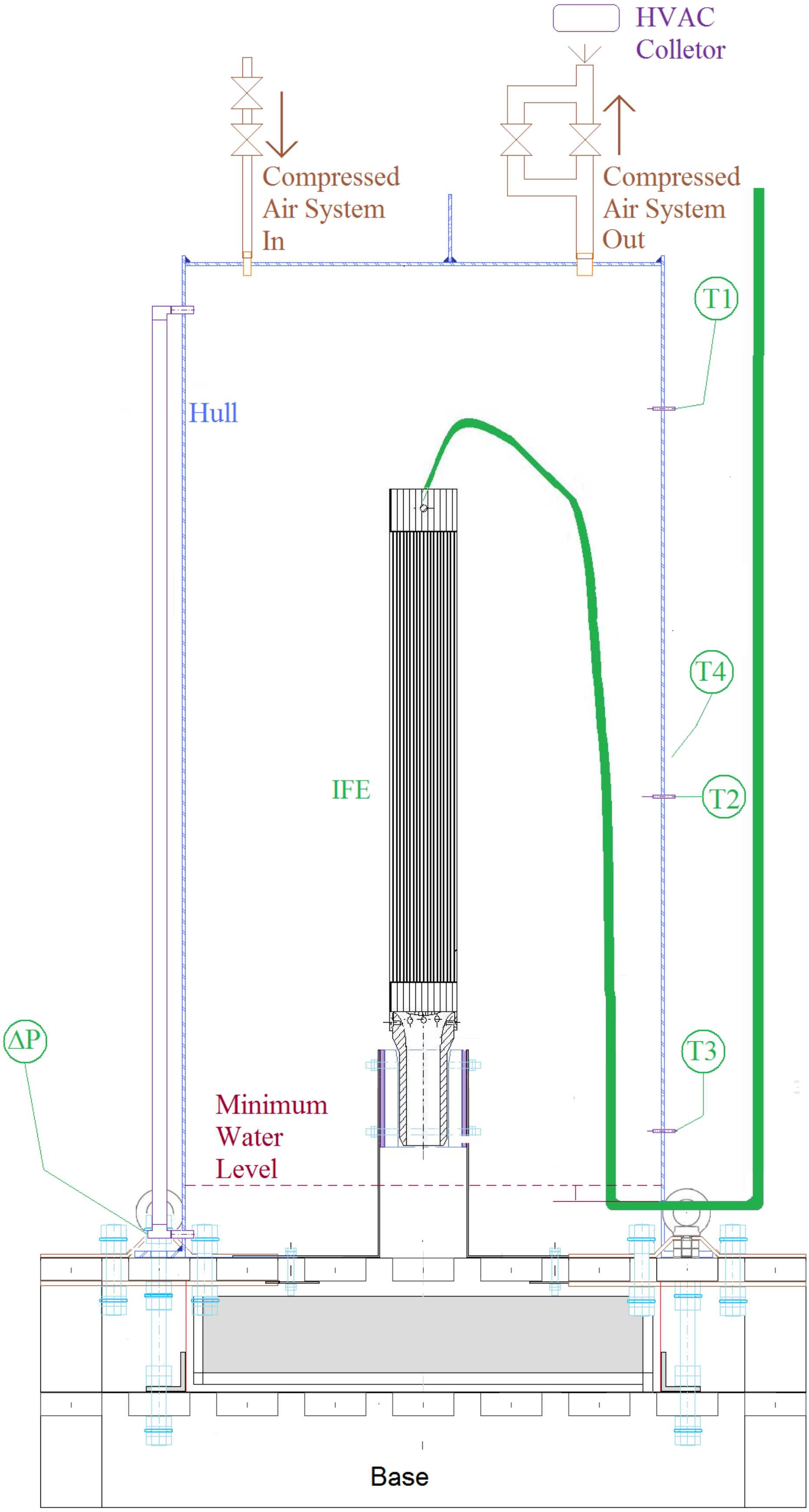

Figure 2: Schematic Representation of the STAR – Elevation.

2.2. Cylindrical Hull

The cylindrical stainless steel hull is of bell type, with locking system at the base by screws and guide pin. Purposely there is no insulation between the hull and the pool. The hull has a level viewer and connections for instrumentation and a plate on its top cover, which allows its transport and placement at the base.

2.3. Compressed Air System

The compressed air system showed in Fig. 2 is responsible for the emptying and filling of water in STAR, being also responsible for the end of the experiment

The system will feature two manual valves in series at the entrance of the section and two in parallel in the same output as a measure of redundancy and security. For the water emptying of the section, or the discovery of IFA, it is required the opening of the two valves in the incoming piping and the closing of the two output valves. For the water filling of the section and the covering of the IFA, and the termination of the experiment, it should be closed one of the two inlet valves and open one of the two output valves.

2.4. Intrumentation

In addition to the temperature measurement by thermocouples of IFA, the instrumentation presented in Fig. 2 will consist of:

- ✓ Measurement of the air temperature in the test section at three positions, with type K thermocouples, to monitor the behavior of the natural circulation of air;

- ✓ Measurement of the pool water temperature (type K thermocouples) beside the test section;

- ✓ Water level measurement in the section using a differential pressure transducer. The section has a transparent PVC tube level viewer. During the experiments, the water level should not be exceeded the minimum value of 2.0 cm above the opening for the IFA thermocouples cables, to avoid compressed air injection into the pool.

All measured data will be collected by the Data Acquisition System (SAD) of the IEA- R1.

2.5. Experimental Position in the Reactor Pool

Fig. 3 shows the positioning of the STAR in the IEA-R1 pool on a platform above the thermal column. A water height of 3.7 m above the section will actuated as shielding for gamma radiation.

2.6. Assembly and Commissioning

Before the experiments, tests should be made on the STAR in the pool and without the IFA, for corrections and adjustments of the assembly and of the operation. Special emphasis will be given to the operation of the compressed air system that is responsible for emptying and filling of the section and the end of the experiment. It should be checked the minimum and maximum times for emptying and filling of the STAR.

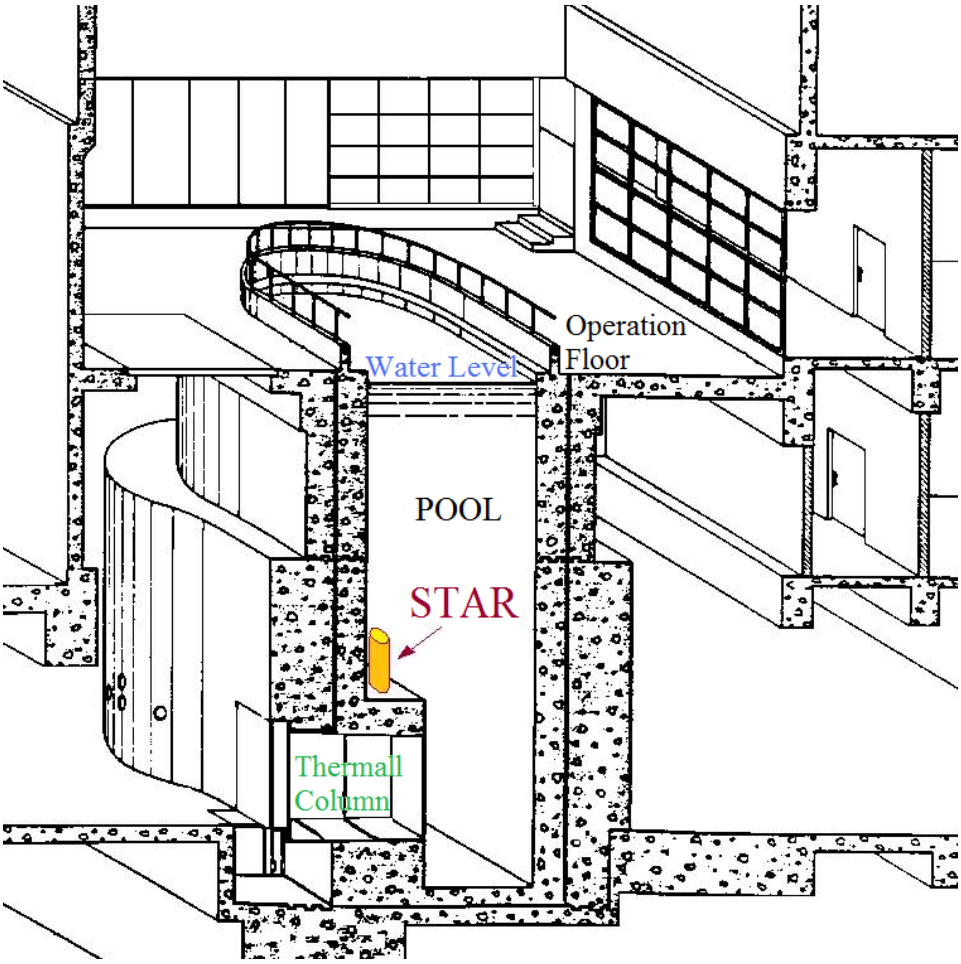

Figure 3 – Positioning of the STAR in the pool of the IEA-R1.

The assembly sequence of the section in the pool for the LOCA experiments will be as follows:

i. To install the base inside the pool (at the location indicated in Fig. 3) using the crane and nylon cables. The total mass of the base is approximately 500 kg;

ii. To remove of the IFA from the core after the time scheduled shutdown of the reactor. Times to remove the IFA will be 64 h and 36 h after shutdown, depending on the experiment (see section 2.7). The IFA is transported by the crane, fully into the pool, and then it is placed in the aluminum nozzle;

iii. To transport the hull by crane. When introducing the hull in the pool, the output valves of the compressed air system should be open (item i) to exhaust the air from inside the hull, and for filling with water. The hull is then positioned and locked at the base through the base bolts and guide pin.

2.7. Loss of Coolant Experiments

Four loss of coolant experiments with the IFA with STAR are previewed:

In T-1 Experiment (T for Total uncovering), the IFA will be totally uncovered with no obstructed air circulation for cooling the IFA. The beginning of the experiment will occur only 64 h after the reactor shutdown, to ensure a significant reduction of the decay heat and the temperatures reached in the IFA. This experiment will be used as a test to validate the procedures and calculation models.

The T-2 Experiment will be identical to the T-1 Experiment, but with time to the beginning of the experiment of 36 hours after the reactor shutdown.

In the P–1 Experiment (P for Partial uncovering), the IFA will be uncovered up to a height below the active length (partial uncovering). In this case, there is an obstruction to natural circulation of the air for cooling the IFA plates. This obstruction is a worst heat removing condition for the IFA and it is very important to be studied. There are only a few information available in literature for this heat transfer condition. The time to the beginning of the experiment will be 64 hours after the reactor shutdown.

The P-2 Experiment will be identical to the P-1 Experiment, but with time to the beginning of the experiment of 36 hours after the reactor shutdown.

Prior to the execution of the experiments, it will be made calculations of the expected cladding temperatures during to the experiments. These calculations aim to the preservation of the integrity of the IFA, and for an estimate of the ending times of the experiments.

All experiments will be interrupted if or when the cladding temperature reaches 100 ^{o}C in the IFA. This value is very below of limit temperature of blistering of the fuel assembly, that is 500 ^{o}C [10] This value was established to protect the IFA against thermal shock.

3. CONCLUSIONS

The design of the STAR test section, and the proposed experiments seek the simulation of two types of LOCA, total and partial uncovering of the IFA, with the attempt of the reproduction of heat transfer conditions similar to those expected in LOCA for RRs.

The STAR section is being designed to ensure the integrity of the IFA and the protection of operators and researchers.

The immediate ending of the experiments when the temperature of the IFA reach the limit of 100 ^{o}C aims to ensure the integrity of it. To finalize the experiment, it will be opened manual valves of compressed air system of the test section. The filling will be done slowly to minimize the thermal shock in the IFA.

The loss of coolant experiments proposed here seek to achieve innovative and safety aspects.

The data obtained in the experiments of partial loss coolant (P-1 and P-2) will be important to validate a model for calculating heat transfer with obstruction of natural circulation in the inner plates.

The comparison of data from experiments T1 with P-1, and T2 with P2 will allow the experimental verification of from which uncovering condition (total or partial) is the most critical for these conditions.

REFERENCES

1. Hamidouche, T., Si-Ahmed E., "Analysis of Loss of Coolant Accident in MTR Pool Type Research Reactor," *Progress in Nuclear Energy* **53**, pp.285-289B (2011).
2. IAEA TECDOC-643, 1992, Research Reactor Core Conversion Guidebook, - Vol 1.
3. Bousbia-Salah A., Meftah B., Hamidouche T., Si-Ahmed E. K.. "A Model for the Analysis of Loss of Decay Heat Removal During Loss of Coolant Accident in MTR Pool Type Research Reactors," *Annals of Nuclear Energy* **33** (2006) 405–414.
4. Wett J. F. Jr., "Surface Temperatures of Irradiated ORR Fuel Elements Cooled in Stagnant Air," Oak Ridge National Laboratory report ORNL-2892, April 6, 1960.
5. D'Auria F, Bousbia-Salah A., "Accident Analysis in Research Reactors," *Proceedings of 15th Pacific Basin Nuclear Conference,* Sidnei, Austrália , outubro de 2006.
6. Hamidouche T., Bousbia-Salah A., Si-Ahmed E. K., D'Auria F., "Overview of Accident Analysis in Nuclear Research Reactors. *Progress in Nuclear Energy* **50** (2008) 7–14.
7. Sedvik B., Yavuz H., "Experimental Measurements for Plate Temperatures of MTR Fuel Elements Cooled in Stagnant Air and Comparison with Computed Results," *Kerntechnik* **63** (1998) 5-6.
8. Yilmazer A., Yavuz H., "Analysis of a Total Loss of Pool Water Accident in MTR-type research reactors," *Kerntechnik* **69** (2004), vol. 69, 154-160.
9. IPEN-CNEN/SP (CCN), Documentação de Qualificação – Elemento Combustível Padrão IEA-208 (Instrumentado com Termopares Tipo K) - U_3Si_2-Al (3,0 gU/cm^3), DQ-CCN-081-00 Jan 2010.
10. Perrotta J. A., "Análise do Projeto dos Elementos Combustíveis do Reator IEA-R1 para a operação a 5 MW," São Paulo: IPEN-CNEN/SP, abr 1997. (Internal Report PSI.REN.IEAR1.002, RELT.007.R00).