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# REACTIVITY EXPERIMENTS WITH DIFFERENT BORIC ACID CONCENTRATIONS IN THE IPEN/MB-01 REACTOR

**Alfredo Abe[1], Andrea Sanchez[2], Mitsuo Yamaguchi[1] and Rinaldo Fuga[2]**

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

[2] Divisão de Física de Reatores
Depto. de Tecnologia de Reatores Nucleares
Centro Tecnológico da Marinha em São Paulo - CTMSP
Av. Prof. Lineu Prestes, 2468
05508-900 São Paulo, SP

## ABSTRACT

According to general design criteria GDC26 (NUREG0800)[1], the reactor design requires two independent shutdown of different design principles must be provided. One of the systems must be capable to holding the reactor core subcritical under cold conditions. The LABGENE reactor was designed in accordance with GDC26, one of the systems uses control rods banks, based on a positive means for inserting the rods and is capable of reliably controlling reactivity changes to assure that under conditions of normal operation, and with an appropriate margin for malfunctions such as stuck rods. The second system is chemical shim based on soluble boron in form of boric acid ($H_3BO_3$), the soluble boron solution is inject directly in the primary circuit.
The objective of this work is to present a series of critical experiments conducted in the IPEN/MB-01 critical facility as part of V&V process of LABGENE reactor core design methodologies.
The experiment was designed to address the boric acid reactivity considering five different concentrations in the reactor moderator at room temperature. All experiments were evaluated and modeled properly with the SCALE system and MCNP Monte Carlo code.

## 1. INTRODUCTION

Nuclear reactor design must ensure safety under all reactor operation condition and to meet these objective, the nuclear design must conform to General Design Criteria[1]. The General Design Criteria (GDC) establish minimum requirement for structures, systems and components important to safety; that provide a reasonable assurance that the facility can be operated without undue risk to health and safety of the public. Specifically there is GDC26, which is basically related to requirement to design of reactivity control system. The reactor design must provides a two independent reactivity control systems of design principles, one of the system shall use control rods banks, preferably including a positive means for inserting the rods, and shall be capable of reliably controlling reactivity changes to assure that under conditions of normal operation, including anticipated operational occurrences, and with appropriate margin for malfunctions such as stuck rods, design limits will not exceeded. Second system must be capable to control de reactivity and one of the systems shall be capable of holding the reactor core subcritical under cold condition. Most of nuclear power design is in accordance and compliance with GDC26, normally one of the reactivity control system is based on control rods banks, and the second is chemical shim using boric acid.

The LABGENE reactor design has a reactivity control system based on control and safety rods banks, the control rods banks is designed to control the reactivity changes due to the temperatures, overcome burnup effect and control the power, and has an appropriate margin to stuck rod condition. The second reactivity control system is designed to shutdown the reactor by means of acid boric injection directly to primary circuit and is capable of reliably hold the reactor core subcritical under cold condition. The aim of this work is present a set of experiments performed at IPEN/MB-01 in order to address the acid boric reactivity.

## 2. IPEN/MB-01 REACTOR AND EXPERIMENT DESCRIPTION

The IPEN/MB-01 is a zero power reactor with fuel rods containing $UO_2$ pellets with uranium enriched to 4.3486 wt.% $^{235}U$, the fuel rods can be arranged in a very flexible configurations, which allows a diversity of critical experiments, the reactivity is controlled by means of only two banks of control rods. The Figure 1 presents a standard schematic view of IPEN/MB-01 reactor core.

Beside flexible core where fuel rods can be arranged in different configurations, the reactor has a specific system designed to insertion and makeup a certain amount of boric acid in the moderator. Thanks to this specific system, the boric acid reactivity experiment was could be performed at IPEN/MB-01 reactor.

Other important reactor data such as fuel composition, dimensions, etc, can be found in a series of critical benchmark experiments performed at IPEN/MB-01[2] during last years.

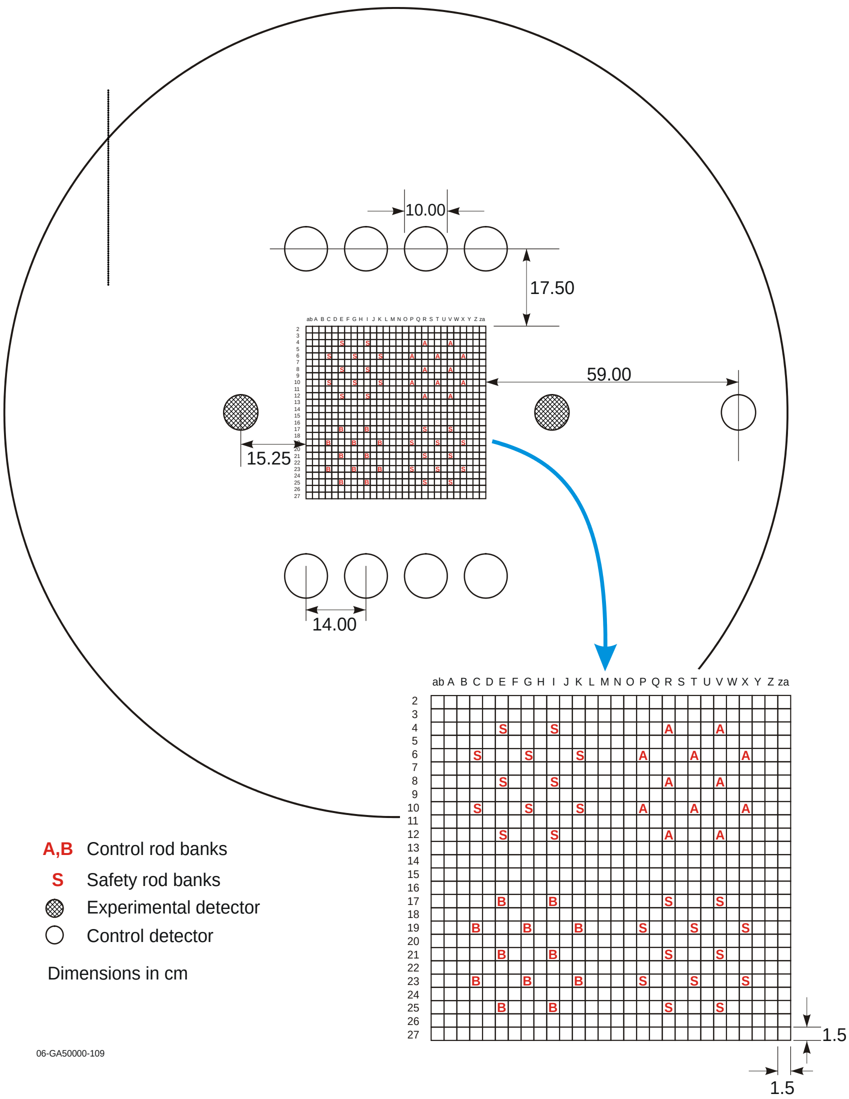


**Figure 1. Schematic Diagram of the Moderator Tank (Plan View) Showing the Detector Distribution around the Core.**

Basically the experiment consist of reactivity measurement due to the presence of boric acid in the moderator, five boric acid concentrations were utilized to address the reactivity. Initially, the volume of water storage tank utilized was determined and properly calibrated in order to be sure about water volume. Before starts the boric acid makeup, some specific well known mass of boric acid was mixed to controlled volume of water, after that laboratory characterization was performed (Chemistry Institute at University of São Paulo). After setup all needed measurement instrumentations and respective calibrations, the experiment began initially considering a reference condition (without any boric acid concentration).

The procedure adopted for the experimental approach was the following: firstly, the reference condition was setup and all relevant data were assessed, specially water temperature was initially kept at around 21.0 °C. The temperature in the fuel region was monitored by the 12 thermocouples strategically located in the reactor core according to Figure 2.

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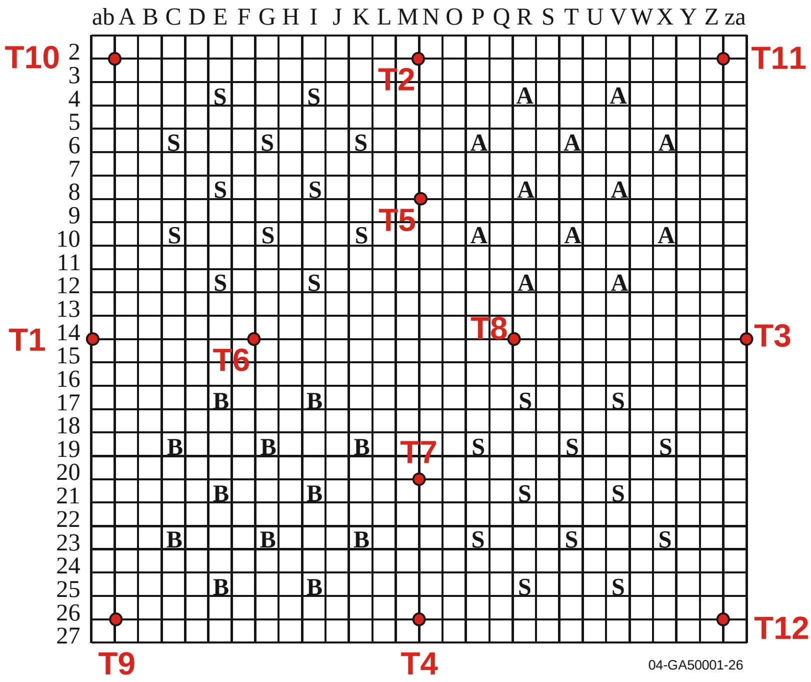


**Figure 2. Horizontal Placement of Thermocouples in the Core.**

The reactivity measurement is obtained by means of reactivity meter, the conversion of detector signals into reactivity is performed by an algorithm based on the inverse kinetic theory. The reactivity meter was set up picking up the signal from a compensated ionization chamber (CIC). This experimental detector was located inside of an instrumentation tube whose center was positioned 152.5 mm away from the outermost row of fuel rods beside the east face of the core (at the three o'clock position in Figure 1). The instrumentation tube is made of aluminum and is 300 cm long. The inner and outer diameters are 9.5 cm and 10 cm, respectively. The reactivity meter was essential to the experiment since it allowed on-line determination of the reactivity as a function of both temperature and control bank position in the core, and for this particular type of experiment, it allows the measurement of reactivity as a function of the water height in the reflector box. All the kinetic parameters used in the algorithm were measured in the facility. Both positive and negative reactivity can be measured by the meter.

Five boric acid concentrations are considered in this evaluation. Each experiment was set up in the following way: specific concentration of boric acid was added to the makeup system, the reactor pump flowed water mixed to boric acid directly to the reactor tank, and control rod bank BC#2 is kept in same position as reference condition. The control rods bank BC#1 was moved to reach a reactor critical state at power level 1W. The mentioned procedure was repeated to other boric acid concentrations. The Table 1 shows the critical position of control rods banks as function of boric acid concentration.

**Table 1. Control Rod Banks Position as Function of Boron Concentration.**

| Boron Concentration (ppm) | Control Rods Banks Withdraw Position |
|---|---|
| 95.742 | BC#1 = 84%<br>BC#2 = WL |
| 43.230 | BC#1 = 83.78%<br>BC#2 = 58% |
| 21.980 | BC#1 = 68.19%<br>BC#2 = 58% |
| 11.028 | BC#1 = 63.10%<br>BC#2 =58% |
| 6.067 | BC#1 = 60.62%<br>BC#2 = 58% |
| 0.00 | BC#1 = 58.70%<br>BC#2 = 58.70% |

## 3. EXPERIMENT ANALYSIS

Calculations were conducted to simulate an experimental setup using a Monte Carlo code MCNP4B[3] and KENO-V module from SCALE System[4] considering a fully detailed modeling. The reactor core model comprises all important and representative regions, including control rods banks and aluminum box. Figure 3 presents main regions considered in the MCNP calculations. Table 2. presents a results obtained using MCNP and SCALE System for five boric acid concentrations.

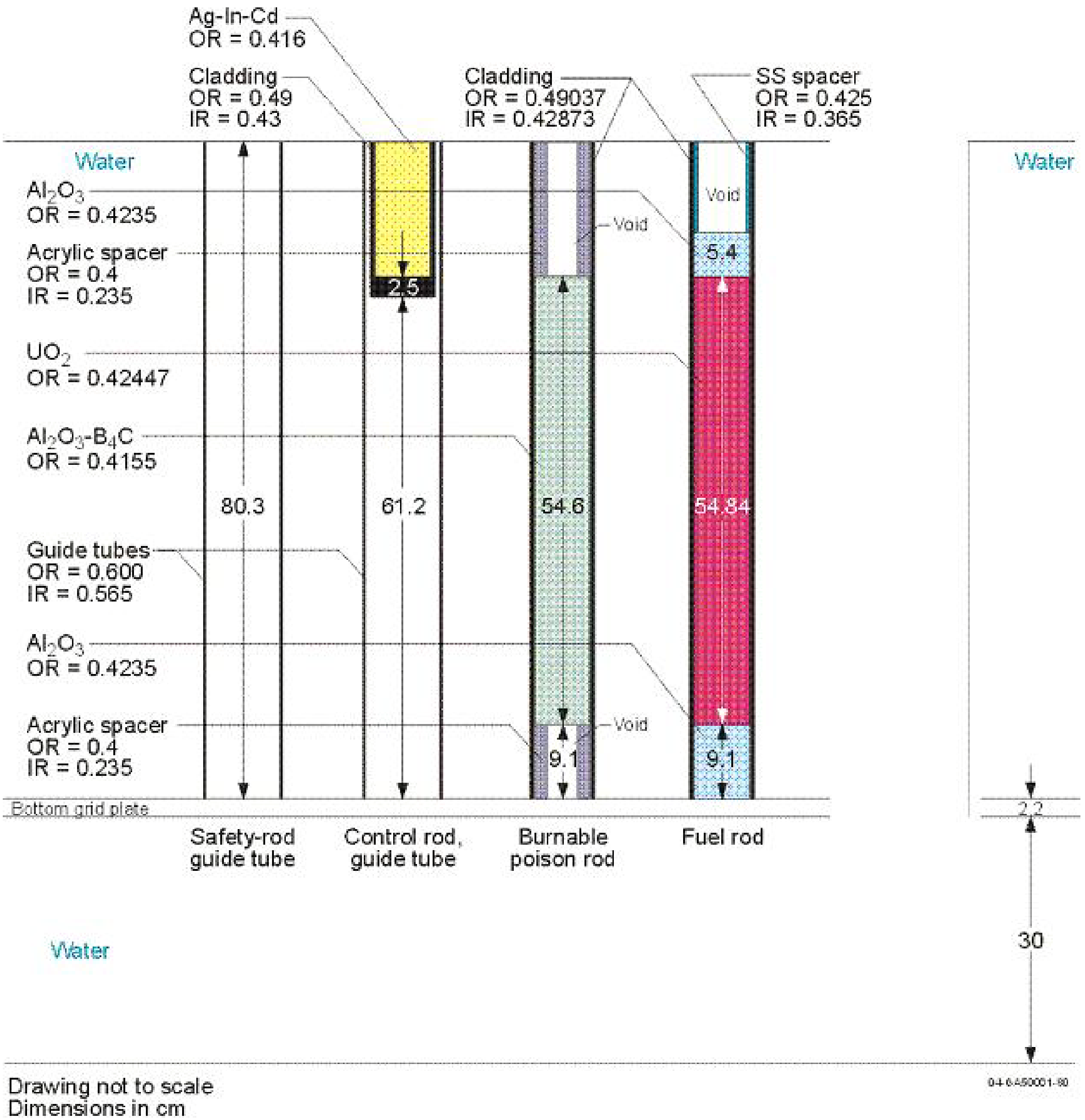


**Figure 3. Representation of the Fuel Rod, the Control Rod Inside its Guide Tubes, the Safety-Rod Guide Tube Models in the MCNP and KENO.**

All MCNP calculations were considered ENDF/B-V cross section library and 40 millions particles to perform criticality calculations. The KENO-V cross sections were 238 energy groups with 40 millions particles.

**Table 2. $K_{eff}$ Results Obtained as Function of Boron Concentration.**

| *Boron Concentration (ppm)* | *Control Rods withdraw position* | *$K_{eff}$ (SCALE)* | *$K_{eff}$ (MCNP)* |
|---|---|---|---|
| 95.742 | BC#1 = 84%<br>BC#2 = WL | 0.9964 ± 0.0001 | 0.99929 ± 0.0001 |
| 43.230 | BC#1 = 83.78%<br>BC#2 = 58% | 0.9962 ± 0.0001 | 0.99883 ± 0.0001 |
| 21.980 | BC#1 = 68.19%<br>BC#2 = 58% | 0.9957 ± 0.0001 | 0.99817 ± 0.0001 |
| 11.028 | BC#1 = 63.10%<br>BC#2 =58% | 0.9960 ± 0.0001 | 0.99836 ± 0.0001 |
| 6.067 | BC#1 = 60.62%<br>BC#2 = 58% | 0.9961 ± 0.0001 | 0.99825 ± 0.0001 |
| 0.00 | BC#1 = 58.70%<br>BC#2 = 58.70% | 0.9967 ± 0.0001 | 0.99916 ± 0.0001 |

The results obtained with MCNP and SCALE code shown generally a very good agreement compared to experimental results. None remarkable deviations or biased results were observed, consequently due to the highest quality of data, those experiments can be considered as critical benchmarks.

## 4. CONCLUSIONS

As a part of validation and verification of reactor physics methodologies applied in the LABGENE reactor core design an experiment with boric acid were performed in the IPEN/MB-01 reactor. Five different boric acid concentrations were mixed to water moderator and control rods bank at critical condition were obtained. All configurations were simulated using SCALE system and MCNP Monte Carlo Code. The results obtained were very consistent and in good agreement with experimental data.

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