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ANALYSIS AND SIMULATION OF THE HOT WATER LAYER (HWL) OF THE BRAZILIAN MULTIPURPOSE REACTOR (RMB)

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Abstract. *The RMB reactor is a research reactor with open pool. It has a nominal power of 30 MW and will produce radiopharmaceuticals, besides testing of fuels and other materials. It was attempted to associate radiological protection alarm triggering of the RMB to various causes, generated by events related to the operation, maintenance and even due to some of the main types of accidents. For analyzes of these causes will be mainly used the commercial software of computational fluid dynamics ANSYS-CFX, in version 16. An experimental device was built to increase the reliability of experimental simulations as the necessary correlations will be held between the two procedures. Furthermore, other software will also be used to compare the results when they are subjected to the same mathematical model with the same initial boundary conditions. So it is expected that this work can modestly assist in the early operating phase of the Brazilian Multipurpose Reactor.*

Keywords: *Thermo-hydraulic, computational fluid dynamics, CFD, hot water layer, RMB.*

1. INTRODUCTION

The Multipurpose Brazilian Reactor consists of an open pool research reactor with 30 MW of power. The RMB is intended to produce a neutron flux applied to the material irradiation for radioisotope production and testing. Figure 1 shows the research reactor OPAL (Open Pool Australian Lightwater Reactor) similar to the RMB, which was built in Australia by the Argentine company INVAP (*Investigaciones Aplicadas*).

Figure 1 - Picture of the reactor OPAL. (ANSTO, 2011)

"Currently, more than 2 million nuclear medicine procedures in about 370 clinics and hospitals in various parts of Brazil are conducted using radiopharmaceuticals, radionuclide produced in nuclear research reactors. Brazil has a growing demand for this type of service. Existing reactors in the country are unable to produce these inputs on a commercial scale, which brings a heavy dependence on foreign suppliers. It is focusing on this external dependence and on increasing the supply to meet the demand of the population that the design of the Multipurpose Brazilian Reactor is being developed." (Rosa, et al. 2013).

The design of the reactor RMB was developed by Argentine company INVAP, and in a way that the operation in the city of Iperó - in the state of São Paulo - can occur with the best efficacy and efficiency, some themes of this project are being studied by Brazilian engineers and researchers.

The RMB deign in conjunction with other existing facilities already made of Labgene and Aramar, will be the largest center of nuclear technology in the country, as it will include a major laboratory infrastructure of nuclear technology.

Figure 2 - Some of the buildings of the RMB project. (Rosa, 2013)

For protection against the radiation emitted by the reactor, it is immersed in a cylindrical pool, where the water acts as a shield. For high power research reactors as the RMB, it is used an independent system that filters and heats the water on the top of the pool, this system creates a hot water layer (HWL), which prevents the rest of the contaminated water from the pool, closer to the core of the reactor, reaches the surface, thereby reducing the radiation dose in the reactor room. Studies of current research reactors, similar to the RMB, demonstrate that a hot water layer, following certain definitions, will reduce by almost 20 times the emission of ionizing radiation in the reactor room.

The HWL fulfills the task of reducing radiation levels on the surface of the reactor pool, establishing a stable, non-radioactive layer of water on the upper region of the pool. The nuclear research reactor RMB will have a nominal power of 30 MW, which will be dissipated in the reactor pool and in the primary circuit that cools the core. However, other systems associated with the reactor and facilities require also, heat dissipation, and will use the same heat sink of the reactor.

The thermal-hydraulics laboratory of CDTN was designated to develop the concept and study the behavior of RMB reactor's HWL. This work summarizes the work performed at the laboratory so far.

1. THE HOT WATER LAYER - HWL

The system of the hot water layer is formed by a circuit with pumps, heating electric resistors, a decay system, filtering by resin and ion exchange column for purification. The HWL functions are:

a) Protect the operators against radiation on the surface of the pools;
b) Provide a means for the continuous cleaning of the water surface;
c) Maintain the visual quality on the surface;
d) Maintain the level of demineralized water during normal operation of the reactor.

"The HWL system should be enabled hours before the reactor start. This process is required for the complete formation of a stable layer of hot water in the service and reactor pools. The hot layer formation process can take several hours, depending on the temperature and condition of the pool water. This is a necessary condition for a normal and safe operation of the reactor" (Santos, 2012).

The work performed aimed to exhaustively do the appropriate analyzes and simulations of conditions that may disrupt the HWL of the pool of the reactor RMB, which is a very important device, related to radiation protection of the team that will work directly with the reactor. At the end of the experimental device construction, it is expected to obtain a bench in the thermos-hydraulic laboratory at CDTN, which can also be used to study other phenomena on research reactors, as well as in accident analysis.

The main goal of this study is to analyze the disturbance causes of the hot water layer, establishing a connection between the radiation rate in the reactor room, and a consequent triggering of the radiological protection system alarm. A three dimensional numerical model will be generated as close as possible to the experimental device. Boundary condition data will be the same for experimental and computational analyzes. And analysis of the transient of interest will be made under this condition.

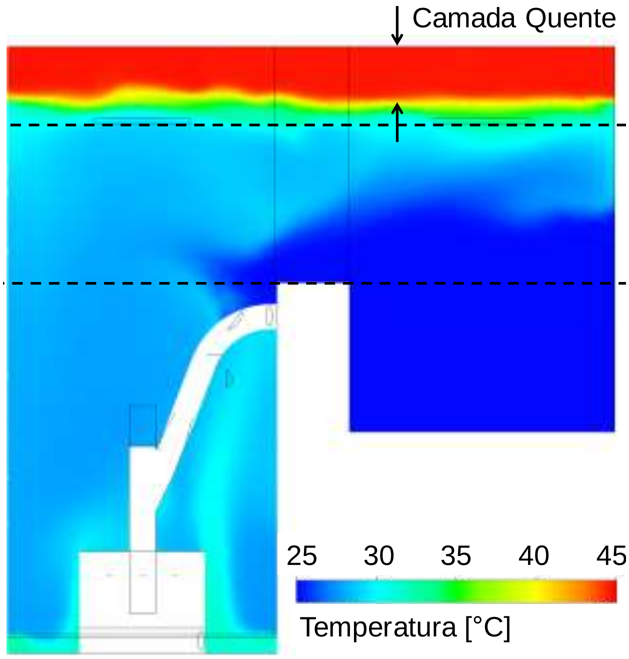

Figure 3 - Stratification analysis in the CFD model. (Schweizer, 2012)

Briefly, the causes of disturbance of the hot water layer will be identified and the radiological effects will be evaluated, with the propensity to be above the standard levels of radiation in the reactor room. Some analyzes will be performed simultaneously with different software for the CFD analysis, however with the same numerical model and with the same input data. This project will also provide an updated set of tools and data acquisition devices, which may be used in future experiments.

3. HWL DESIGN AND ANALYSIS HISTORY

We will describe below the diverse tests and activities that have been made until this date, where the main details of each work are presented:

3.1. CONCEPTUAL PROJECT

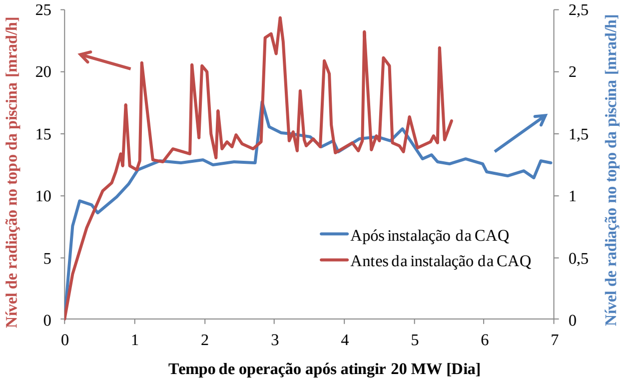

Figure 4 - Radiation graphic at the top of the HANARO's pool. (Navarro, 2011)

First, a study was conducted based on the report SAR / PSAR of the OPAL reactor (Australia), to set a preliminary conceptual design of the HWL of the RMB. Moysés Alberto Navarro, RMB-11200-MS-001. Description of the hot layer and purification systems, 2011. These studies determined the following parameters: the description of the hot water layer and purification system (HWLPS) of the RMB project; the reliability characteristics of the project; HWL system primary design; required heating power calculation of the HWL and the theoretical radiation level on the surface of the RMB pool.

3.2. MODEL NUMBER OF RMB

Next on the work sequence, it was reported the simulations and studies made to conclude the conceptual design. André Augusto Campagnole Santos, RMB-11600-MS-001, Hot water layer system description, 2012. These studies aimed to determine the characteristics of the pumps, heaters, vacuum pumps, vacuum tank, ionic exchange columns of the HWL and filter of resin retention. Also of the HWL control instruments for: flow, temperature and water level. With ANSYS CFX software in its 14th version, simulations were performed to study the injection and removal position of the pool, attenuation, transients, etc.

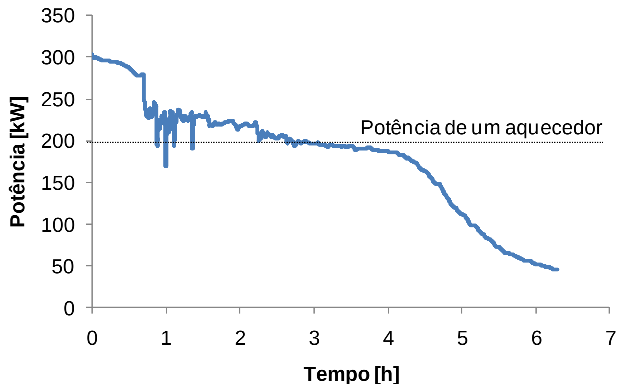

Figure 5 - Heating power necessary for the RMB operation. (Santos, 2012)

3.3. VALIDATION EXPERIMENT ELABORATION

In this step, the validation experiment was described through three works:

3.3.1. Fernando Lage Araujo Schweizer, RMB-N01-00-PC-11600-PL-001, Plan of the Conceptual Validation Experiment of the Hot Water Layer and Purification System (HWLPS) Transient on the RMB - Iperó, 2012. This plan aimed to detail the construction of a testing bench in reduced scale of the RMB pool for the study of the Hot Water Layer System. In the designed experiment, when completed, temperature local speeds will be measured for different RMB operating conditions. Noting that the numerical results cannot be considered without its proper validation, as this is caused by the low sensibility of turbulence models.

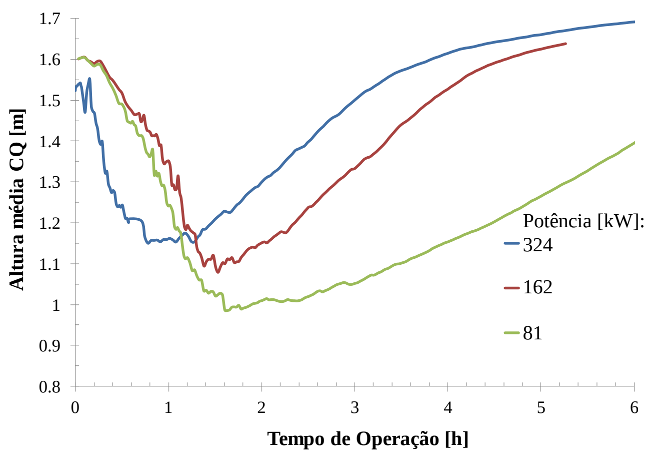

Figure 6 - Average height of the HWL, initially at 45° C during the reactor operation for different heating powers. (Schweizer, 2012)

3.3.2. Graduation Work of Fernando Lage Araújo Schweizer, Numerical investigation of the pool overflow of the Multipurpose Brazilian Reactor, UFMG, 2012. In this work a study of behavior of the hot layer of the RMB was made, since its formation, and at the conditions that cause movement on the HWL. Using ANSYS CFX software, version 14, the turbulence models, the water input and output in the circuit, the power heaters, the temperature of formation of the

HWL and the theoretical radiation dose rate during operation of the reactor were all evaluated for the analysis of the RMB's project.

3.3.3. Master's thesis of Fernando Lage Araujo Schweizer, Numerical analysis and design of an experiment in reduced scale of the hot water layer system of the Multipurpose Brazilian Reactor, UFMG, 2014. In this dissertation a study of the HWL behavior during the first hours of operation of the reactor was made. Applying dimensionless analysis, the design of the components of the reduced experimental device was made in a 1/10 scale of the reactor pool. Also it was defined the equipment and sensors of the testing bench project.

3.4. EXPERIMENT CONSTRUCTION AND COMMISSIONING

The experimental device is now in the final stages of construction, the instrumentation is being installed and the data acquisition system is being tested, using the PYTHON software. The design, the construction of the bench and the instrumentation assembly, were all entirely developed internally, in the SETRE-CDTN laboratory.

Figure 7 - Experimental device photo. (Santos, 2015)

4. REDUCED PHYSICAL MODEL FOR EXPERIMENTS

The theory of similarity among models states that to build a model of experiments device, the dimensionless number that will be considered for the analysis of the HWL is the densimetric Froude number, which relates the inertial and buoyancy forces. The calculation of the load loss of the reduced model was made from the assembly performed in the laboratory of the SETRE-CDTN. The reactor pool tank had to be adapted to a square section, but keeping the volume scale.

5. CONDITIONS DISORDER ANALYSIS OF THE HWL

The hot water layer may have its characteristics changed by operating factors or due to maintenance or also due to accidents. The evaluation of research reactors project resulted in the identification of various types of failures. The following are some of the items that may disturb the hot water layer (HWL):

- Change in the pumping flow rate;
- Valves opening.
- Electrical power supply loss;
- Object fall on the surface of the pool;
- Refrigerant loss;

- Heavy water system loss;
- Seismic activities;
- Samples loose in the bottom of the pool.

6. CONCLUSION

The main goal of this work is to associate the radiological protection system of the RMB to the occurrence of events caused by the operation, maintenance and even by accidents of high probability. After assembling the device for experiments, tests will be performed on computer models to have their results compared with the experimental. In case there is a good correlation between the results, we will study possible conditions, with greater potential, that disturb the HWL. Thus with the information that will be obtained in this work, it is expected that they can be used by the RMB operation personnel as a prior action against daily problems and also in the development of failure risk prevention procedures.

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