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RELAP5-3D MODELING OF THE BRAZILIAN MULTIPURPOSE REACTOR

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Abstract. *This work presents the steady state thermal hydraulic calculations of the Brazilian Multipurpose Reactor (Reator Multipropósito Brasileiro - RMB) using a RELAP5-3D model. The RMB is currently being projected and several analyses are being performed. It will be a 30 MW open pool multipurpose research reactor with a compact core using Materials Testing Reactor (MTR) fuel assembly with planar plates. RMB will be cooled by light water and moderated by beryllium and heavy water. The results of RELAP5-3D simulations for the RMB (pool and core temperatures) were analyzed and compared with reference data presenting good agreement between them. An accident was analyzed (Loss of Electric Power) and the results also were compared with RELAP5-MOD3.3 data presenting good agreement of the results of both codes.*

Keywords: *RMB, Relap5, Research Reactor*

1. INTRODUCTION

The RELAP5-3D© code is a successor of the RELAP5/MOD3 code. This new version contains several important enhancements over previous versions of the code. The most prominent attribute that distinguishes the RELAP5-3D© code from the previous versions is the fully integrated, multi-dimensional thermal-hydraulic and kinetic modeling capability. This removes any restrictions on the applicability of the code to the full range of postulated reactor accidents (RELAP5-3D, 2005).

The Brazilian Nuclear Energy Commission (*Comissão Nacional de Energia Nuclear* - *CNEN*) is leading the project of the Brazilian Multipurpose Reactor (*Reator Multipropósito Brasileiro- RMB*) envisaged to be designed, constructed and operated to attend the Brazilian need for a multipurpose neutron source, which will be able to supply the demand of radioisotopes, carry out material tests and develop scientific, commercial, and medical applications with the use of neutron beams.

The Australian research reactor Opal projected by Argentina and built in Australia is being used as an initial reference for the RMB project.

In the present work, a nodalization for the RELAP5/MOD3.3 and RELAP5-3D of RMB core and of the most important components of the pool loop and core loop are presented, where the steady state results and a Loss of Electric Power Accident have been analyzed and compared.

2. BRAZILIAN MULTIPURPOSE REACTOR

The RMB will be an open pool multipurpose research reactor with a compact core, using MTR fuel assembly type with planar plates, and will be cooled by light water and moderated by heavy water and beryllium. Table 1 presents the main characteristics of the RMB. Figure 1 shows the present conceptual model of the RMB reactor (CNEN, 2010) that was based in the Australian research reactor Opal (ANSTO, 2001).

A tank with heavy water surrounds three faces of the chimney in the core area working as a reflector and enabling the extraction of neutron beams and placement of materials for irradiation. In the remaining face, beryllium is used as a reflector. The heavy water temperature will be controlled by a dedicated cooling system.

The whole core structure will be located within a squared cross-section channel, ñcore chimneyò, which is part of the primary cooling circuit. The core will be cooled by a flow of demineralized light water moving upwards through the core. In normal operation, the coolant is pumped through the core and then to the pipes to a heat exchanger before returning to the core inlet.

The reactor and pools temperatures are controlled by four circuits: Hot Water Layer (HWL), Primary Cooling System (PCS), Reactor and Service Pools Cooling System (RSPCS) and Reflector Cooling System (RCS).

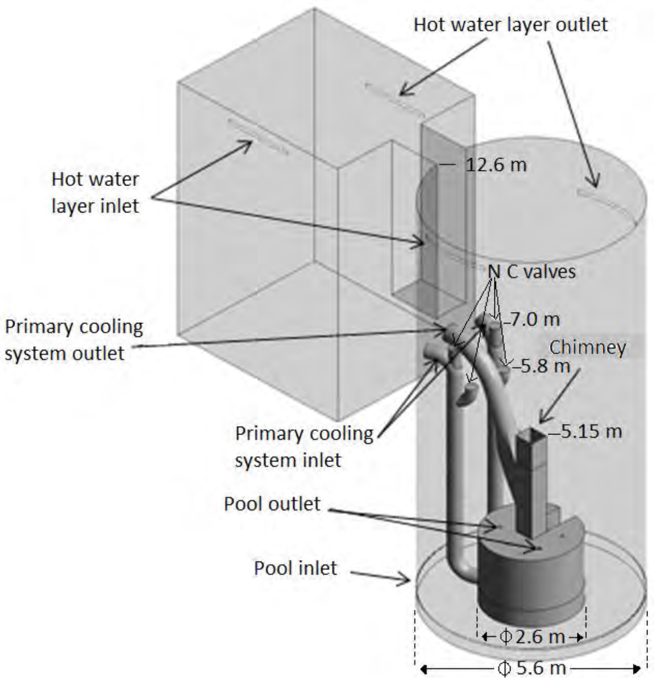

Figure 1. RMB present concept.

Table 1. General characteristics of the RMB

Reactor	
Nominal Power	30 MW
Coolant	Light water
Reflector	H_2O, D_2O, Beryllium
Thermal and fast neutron flux in the core	> 2.0 x 10^{14} neutrons.cm^{-2}.s^{-1}
Core	
Flow direction in core	Upward
Location control rods drive	Below core
Grid array	5 x 5
Dimensions	0.51 x 0.55 x 0.815 m
Number of fuel / control elements	23 / 6
Absorbing material	Ag-ln-Cd
Fuel assembly type	MTR (LEU)
Nuclear fuel	U_3 Si_2-Al enriched at 20%
Fuel density	4,8 gU/cm^3
Cooling	
Core / pool inlet coolant temperatures	311 / 306 K
Mass flow rate from pool to chimney	83.3 kg/s
Core mass flow rate (inlet/outlet)	750.0 / 833.3 kg/s

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3. THERMAL HYDRAULIC MODEL

Figure 2 shows the RELAP5 nodalization developed to simulate the RMB. Table 2 shows the correspondence between the main plant component and their equivalent node in the nodalization scheme. The reactor pool was modeled using two pipes components (100 and 130) composed by twenty volumes each one. The service pool was modeled using a pipe component (150) with twelve volumes. Volume 140 is a branch component that represents the upper pool surface, which is in contact with the atmosphere. Volume 190 is a time dependent volume that simulates the atmosphere on the top of pool surface.

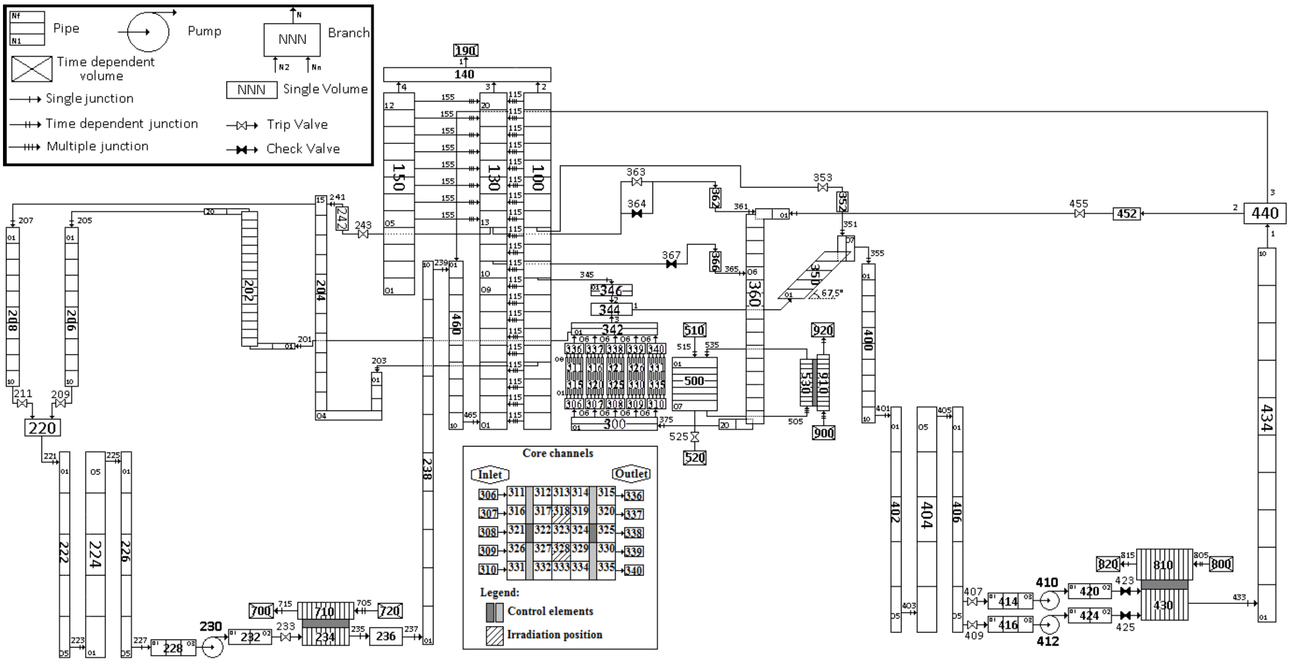

Figure 2. RMB nodalization for RELAP5

Table 2. Correspondence between the main plant components and their equivalent node in the RELAP5 nodalization scheme.

Component	Identifier
Reactor pool	100 and 130
Reactor Pool Cooling System (RPCS)	201-239
Reactor core	311-335
Reactor chimney	346
Primary Cooling System (PCS)	400-460
Heavy water tank	500
Reflector Cooling System (RCS)	500-530
Natural Convention Valves (Flap Valves)	364 and 367
Siphon breakers valves	243, 363 and 353
Pool atmosphere simulator	190
Decay tank of PCS	402-406
Decay tank of RPCS	222-226
Pumps of PCS	410 and 412
Pump of RPCS	230
Secondary side heat exchanger of PCS	800-820
Secondary side heat exchanger of RPCS	700-720
Secondary side heat exchanger of RCS	900-920

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The RSPCS removes heat from both pools and from the irradiation rigs located in the heavy water reflector structure.

The Primary Cooling System (PCS) comprises components 300 through 360 which are inside the pool and components 400 through 460 which are outside the reactor pool. Component 300 represent the core inlet lower plenum which conducts the light water to the core (components 311 to 335). The core has twenty-five hydrodynamics channels with twenty-three Heat Structure (HS) representing the fuel elements. There are two irradiation position on the core (components 318 and 328). The heated water flows through the components 342 (core outlet upper plenum) and 344 where it is mixed with a small downward flow coming from the pool through the chimney (component 346). The chimney flow corresponds about 10% of the total outlet flow of the PCS.

The Reflector Coolant System- RCS is composed by a heavy water tank (component 500) and its heat exchanger circuit (component 530- primary side and component 910- secondary side).

The area located on level -5.00 m (under the pool ground level) accommodates the pumps of the cooling systems, heat exchangers and associated components of both circuits PCS and RSPCS.

The point kinetics model was used to estimate the fuel power in the simulations in the RELAP5-MOD 3.3 and also in the RELAP5-3D.

4. STEADY STATE CALCULATION

Several thermal hydraulic parameters have not been established in the RMB project and frequently there are changes on their values and definitions. Experiments to verify the RMB behavior are still being planned and therefore, there are not experimental data to compare with the results of RELAP5. However, the mass flow rate and temperature in the core has been defined based in the Opal reactor and they have been used as input data for the RELAP5 model. Table 3 shows the steady state calculations with RELAP5-MOD 3.3 and RELAP5-3D models performed at 30 MW and the comparison with some reference values. As it can be seen in Table 3, the analyzed steady state parameters showed very good agreement with the reference considering the RELAP5 (MOD 3.3 and 3D) users acceptable error. The results from the RELAP5-3D showed little difference in relation to the RELAP5-MOD 3.3, mainly for the mass flow rate parameter.

Table 3. Reference and calculated results for 30 MW power condition.

Parameters	Reference	RELAP5-MOD 3.3	Error (%)(3)	RELAP5-3D	Error (%)(3)	Acceptable Error (%)
Inlet and outlet core coolant temperatures (K)(1)	311.0 / 320.0	310.0 / 319.0	0.3/0.3	310.0 / 319.1	0.3/0.3	0.5
Inlet and outlet pool coolant temperatures (K)(1)	306.0 / ---	306.3/ 307.2	0.1	306.3/ 307.2	0.1	0.5
Mass flow rate from pool to core by chimney	83.3 kg/s	83.2 kg/s	0.1	82.7 kg/s	0.7	2.0
Inlet and Outlet core mass flow rate (kg/s)(2)	750.0 / 833.0	749.1 / 832.3	0.1 / 0.1	743.5 / 826.2	0.8 / 0.8	2.0

(1)(ANSTO, 2001)
(2)(Torres and Macedo, 2012)
(3)Error = 100×(calculationī experimental)/experimental.

5. TRANSIENT CALCULATION

Postulated Initiating Events (PIEs) are events that have the potential to challenge the safety limits of the plant. They are the initiators of fault sequences. The primary causes of a PIE may be equipment failure and operator errors (both within and external to the reactor facility) and human-induced or natural events.

Following the guidance of the IAEA, a set of PIEs is assembled for assessment against the design of the Replacement Research Reactor. This list covers all aspects of the design, operation and utilization of research reactors (ANSTO, 2001).

The loss of electric power is itself not an initiating event but, in general, regulations require analysis of the behavior of the facility under such event. Then, loss of electric power was simulated and analyzed in this work as described in the next section.

5.1. Analysis of the loss of electric power

When the reactor has a reliable standby power supply system (e.g. appropriately qualified diesel generators), it is only necessary to analyze loss of normal power. When reliability of the system cannot be assured, loss of standby power

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needs to be evaluated as well. Low power reactors that can be cooled by natural circulation may not have a standby power supply beyond uninterruptible power systems (batteries) for instrumentation and control. The high power MTRs may have diesel generators and rely on their functioning for decay heat removal (IAEA, 2008).

For this simulation with the RELAP5 code, three trips were actuated at the same time in order to simulate the accident. As a consequence of such trips, actuation of the PCS pumps (410 and 412) were turned off and the RPCS pump (230) was turned off in the same time.

The transient event was started at 20,000 seconds after the simulation of a 30 MW steady state. The Figure 3 shows the power evolution during 50,000 s of simulation, where itǿs possible to see that the power decreases exponentially until to reach 200 KW of power to both RELAP5 models. This residual power is due to the heat generated by fission product.

To simulate the First Shutdown System (FSS) action (insertion of all control plates in core) using the RELAP5, a negative reactivity of $10 is inserted in 0.5 seconds of simulation time. This process starts when the mass flow in core inlet decreases below 10% of steady state value or if the reactor pool level decreases below 10.8 m.

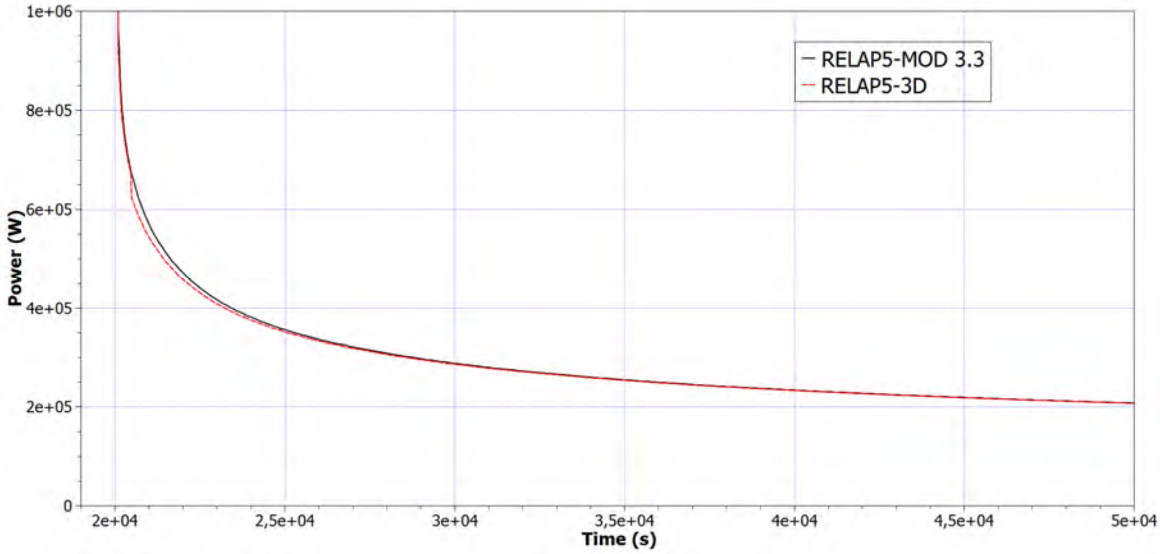

Figure 3. Power evolution during the transient.

Figure 4 shows the evolution of coolant temperatures at the bottom and top of the reactor pool. As it can be seen, after the event starting, the reactor pool temperature began to increase. In the steady state condition, the temperature difference between the bottom and the top of the reactor pool is less than 1 K. However, after the event, this difference increases and, at 50,000 s it reaches 2 K. In a general way, the results between RELAP5-MOD 3.3 and RELAP5-3D are in good agreement.

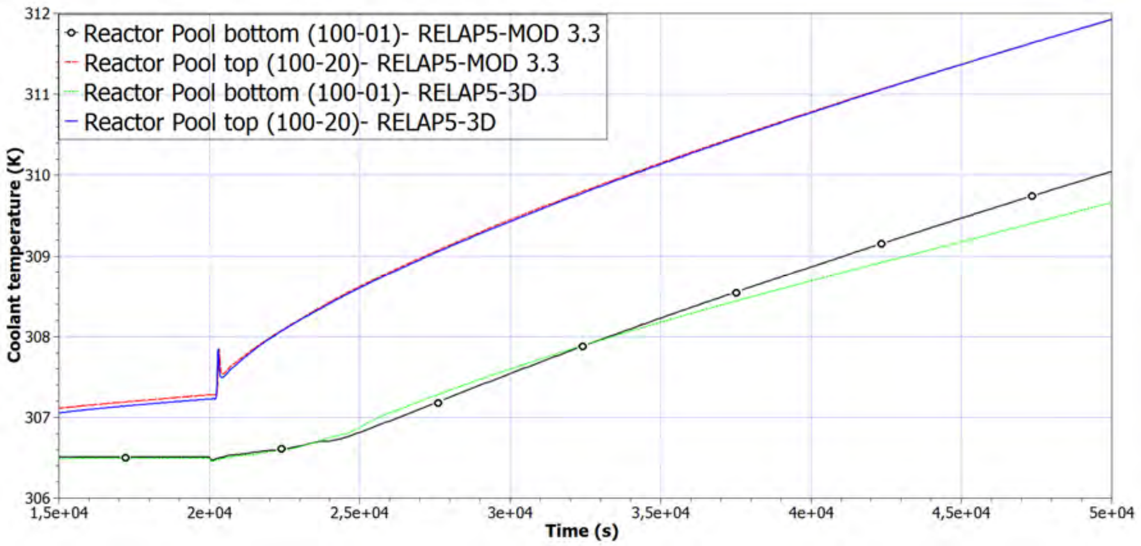

Figure 4. Coolant temperature in the reactor pool during the transient.

Figure 5 shows the time evolution of the mass flow rate in the component 344, chimney outlet, core outlet and Primary Cooling System (PCS) outlet for the RELAP5-3D. The RELAP5-MOD3.3 presented exactly the same behavior as the RELAP5-3D. The details shows the mass flow rate evolution enlarged; it is possible to see perfectly that the mass flow rate in the PCS outlet (344-01) assumes null value due to the isolation of this circuit. Before the loss of electric power to occur, the mass flow through the chimney was downward. However, during the natural circulation phase, it is upwards carrying the heat from core to reactor pool. The mass flow rate through the core decreases up to the opening of the check valves (364 and 368) reestablishing the natural circulation. The natural circulation mass flow rate is very small, about 12 kg/s, but it is enough to cool fuel elements and to transfer the generated heat to the pool.

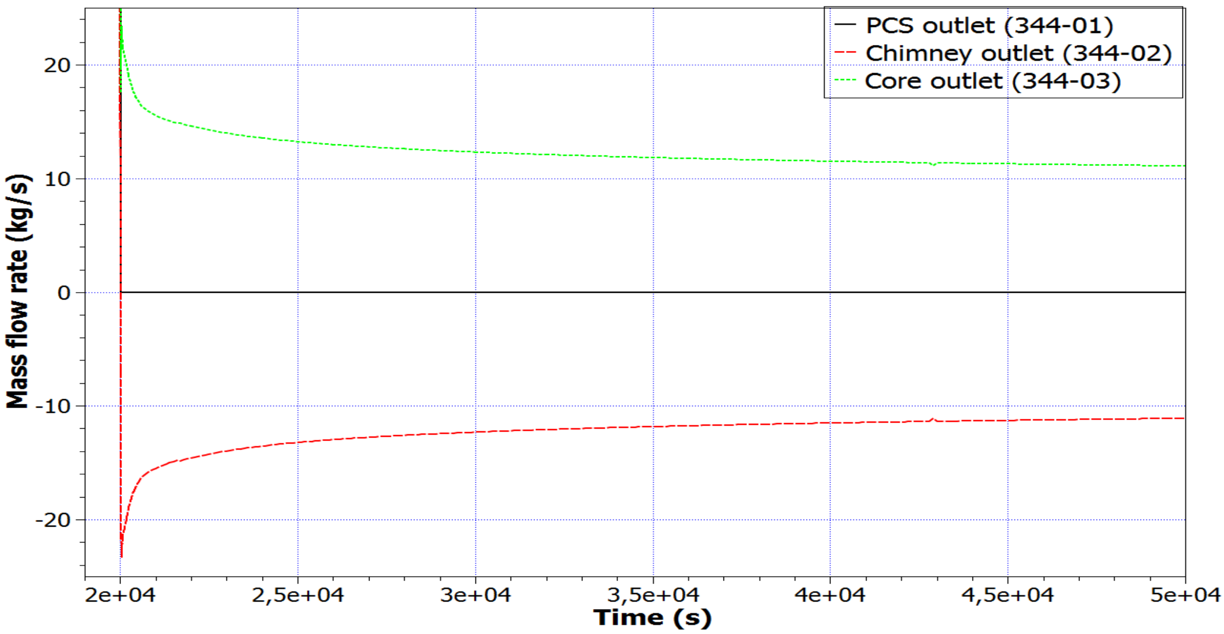

Figure 5. Mass flow rate evolution in the component 344 calculated by RELAP5-3D.

6. CONCLUSIONS

The Brazilian Multipurpose Reactor (RMB) will have many functions with the main utilization for production of radioisotopes to medical applications. Several characteristics of the OPAL reactor have been used in the initial project of the RMB. The development of the RMB reactor is on phase of theoretical calculations.

The thermal hydraulic model in the RMB is presented in this work using RELAP5-MOD3.3 and RELAP5-3D codes. In both codes was used point kinetic simulation. After several tests the steady state operation condition was reached at 30 MW with all thermal hydraulic parameters in stable behavior. Thereafter, a loss of electric power transient was simulated.

To simulate this accident the recirculation pump was turned off, the reactor was shutdown and the Primary Cooling System was isolated. This event induced a large reduction of mass flow rate in the core and consequently the core and pool coolant temperature increased slowly. However, up to 50.000 seconds of calculation, the coolant did not reach the saturation point. The check valves opened correctly showing that the natural circulation mode was established showing to be enough to keep the core cooled during an extreme event like that. Analyzing the results, the RELAP5-3D model demonstrated to simulate satisfactorily the behavior of the RMB according with comparisons with the RELAP5-MOD3.3.

The next step of this work will be to implement the 3D-neutronic simulation of the RMB in the RELAP5-3D to reproduce, in a more realistic way, transients that cannot be simulated duly using point kinetic model.

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9. RESPONSIBILITY NOTICE

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