ANALYSIS OF POSTULATED LOSS OF COOLANT ACCIDENTS ON BRAZILIAN MULTIPURPOSE REACTOR USING RELAP5

Humberto Vitor Soares, hvs@cdtn.br
Antonella Lombardi Costa, antonella@nuclear.ufmg.br
Claubia Pereira, claubia@nuclear.ufmg.br
Maria Auxiliadora F. Veloso, dora@nuclear.ufmg.br
Patrícia Amélia de Lima Reis, patricialire@yahoo.com.br
Departamento de Engenharia Nuclear, Universidade Federal de Minas Gerais, Av. Antônio Carlos, 6627 – Campus UFMG, PCA1 – Anexo Engenharia – Pampulha, CEP 31270-90 Belo Horizonte, MG, Brasil
Instituto Nacional de Ciências e Tecnologia de Reatores Nucleares Inovadores/CNPq, Brasil

Ivan Dionysio Aronne, aroneid@cdtn.br
Centro de Desenvolvimento da Tecnologia Nuclear/Comissão Nacional de Energia Nuclear – CDTN/CNEN, Av. Antônio Carlos, 6627, Campus UFMG, Belo Horizonte, Brasil.

Abstract. *The Brazilian Multipurpose Reactor (RMB) is currently being projected and several analyses are being carried out. It will be a 30 MW open pool multipurpose research reactor with a compact core using Materials Testing Reactor (MTR) type fuel assembly with planar plates. RMB will be cooled by light water and moderated by beryllium and heavy water. This work presents the calculations of steady state operation of RMB using the RELAP5 model and also three cases of loss of coolant accident (LOCA), in the reactor and service polls cooling system (RSPCS) inlet and two cases in the primary coolant system (PCS), inlet and outlet. In both cases the coolant pool level decreased until 7 m, keeping the core covered by water, but in different times. Natural circulation mode was established in the reactor pool and consequently the decay heat was removed keeping the integrity of the fuel elements.*
Keywords*: Research reactor, LOCA, RELAP5.*

1. INTRODUCTION

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 of RMB core and of the most important components of the pool loop and core loop are presented and three LOCA cases have been analyzed.

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 model of present concept 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, “core chimney”, 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 via 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).

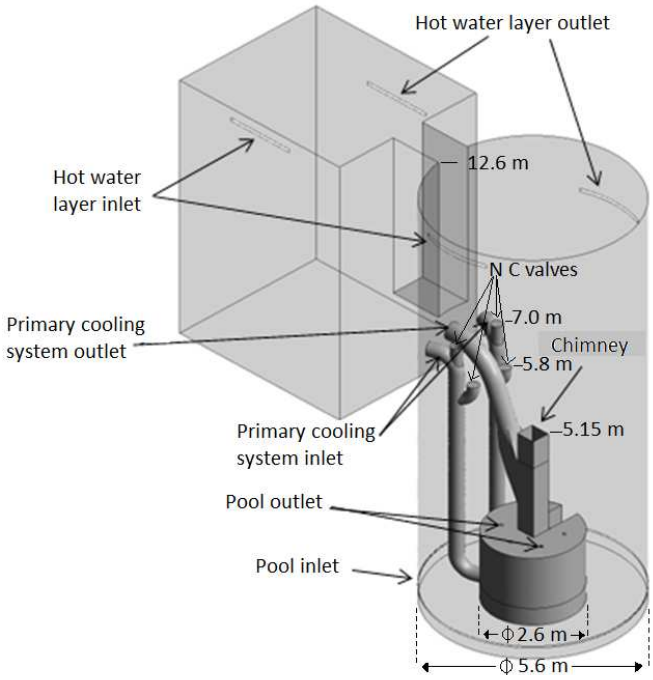

Figure 1. RMB present concept.

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

3. THERMAL HYDRAULIC MODEL

Figure 2 shows the RELAP5 nodalization developed to simulate the RMB and it shows the different positions of the LOCA valve (601) and time dependent volume (600), which simulates a recipient that receive the coolant during the three simulated accidents. These components are painted of red and are located in the RSPCS inlet, PCS inlet and outlet. 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.

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 (component 316). The core has one hydrodynamic channel with only one Heat Structure (HS) associated to it representing all fuel plates. The heated water flows through the components 320 and 330 where it is mixed with a small downward flow coming from the pool through the chimney (component 340). 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.

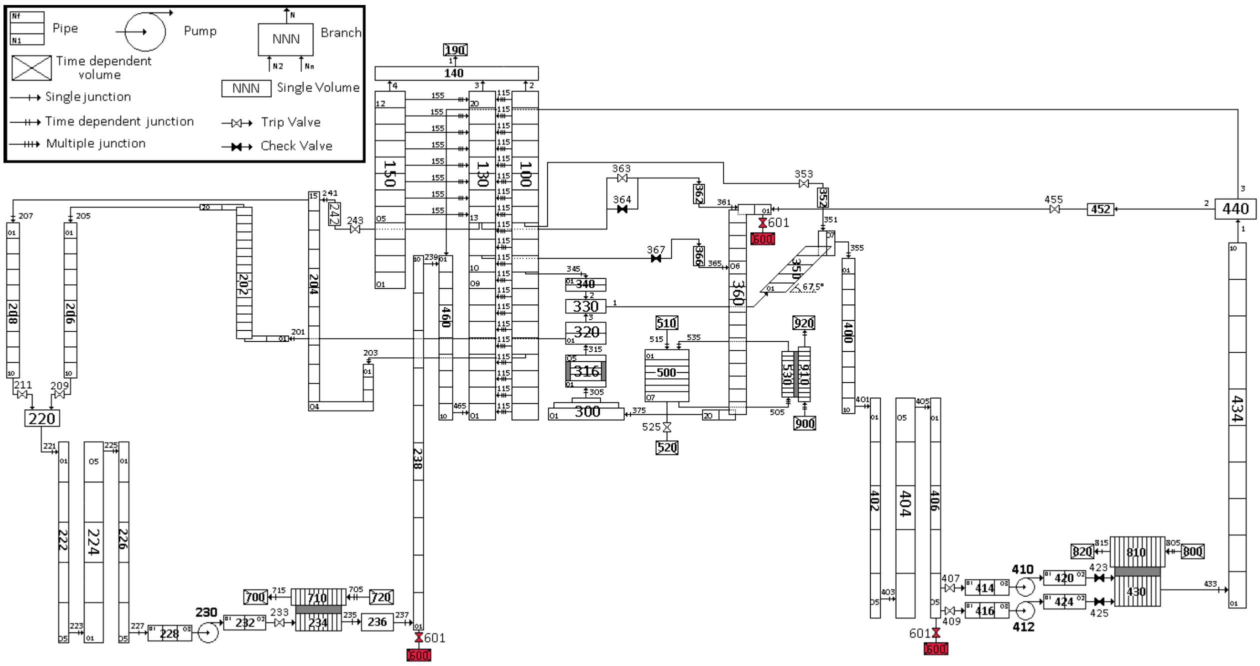

Figure 2. RMB nodalization for RELAP5 highlighting the position of the LOCA events.

Component	Identifier
Reactor pool	100 and 130
Reactor Pool Cooling System (RPCS)	201-239
Reactor core	316
Reactor chimney	340
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
Primary side heat exchanger of PCS	430
Secondary side heat exchanger of PCS	800-820
Primary side heat exchanger of RPCS	234
Secondary side heat exchanger of RPCS	700-720
Primary side heat exchanger of RCS	530
Secondary side heat exchanger of RCS	900-920

4. ANALYSIS OF LOSS OF COOLANT ACCIDENT

The loss of coolant accident (LOCA) is one of the most important design basis accidents. In spite of the probability of large break accident in research reactors is very low it might cause core damages in the case of its occurrence.

Three cases are analyzed in this paper:

- Case 1: LOCA in RSPCS inlet;
- Case 2: LOCA in PCS inlet;
- Case 3: LOCA in PCS outlet.

Analyses of the all cases are very similar, because in the begin of LOCA the coolant goes out by rupture and the water level of the reactor pool drops until the upper flap valves, which will act as siphon breakers and will prevent the water level from dropping below level +7.00 m. The lower flap valves will open, thus creating the natural circulation cooling flow path. Only one of the two valves is required to provide a flow sufficient to remove core decay heat.

All transient events started at 20,000 seconds, after the simulation of steady state at 30 MW. 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.

Table 3 presents the summary of all 3 cases. The time to reach the siphon breaker valves depends on the flow rate through the rupture, which depends on the pipe diameter and the pressure of the circuit. In the steady state the core outlet temperature is 319 K; during the event the maximum temperature reached was by the core was 335 K for case 1. The cladding temperature for steady state is 354 K reaching maximum value of 357 K for case 1. In all analised cases, the increase in the temperatures due the LOCA event did not represent danger situation for the core safety.

Table 3. Summary of the loss of coolant analyses.

Cases	Diameter of the pipe (mm)	Time to reach siphon breaker level (s)	Maximum flow rate by rupture (kg/s)	Maximum temperature in the core outlet (K)		Maximum temperature in the cladding (K)	
				Steady State	LOCA	Steady State	LOCA
1	500	185	1477	319	335	354	357
2	601	159	2606	319	324	354	355
3	809	109	2531	319	334	354	356

5. CONCLUSIONS

The reactor remains in a safe state during the LOCA transients. The temperatures of the fuel assemblies do not exceed safety limits. The heat fluxes in the core channel remain below those needed for departure from nucleate boiling and flow instability. There would be no radiological impact on the public due to a Primary Cooling System or Reactor and Service Pools Cooling System LOCA. The maximum cladding surface temperatures are well below the onset of nucleate boiling value (400 K). The coolant temperature remains below saturation. The heat generated by the rigs and the core were removed by natural circulation.

6. ACKNOWLEDGEMENTS

The authors are grateful to CAPES, CDTN/CNEN, FAPEMIG and CNPq for the support.

7. REFERENCES

ANSTO, 2001. Preliminary safety analysis report for ANSTO replacement research reactor facility.

CNEN, 2010. Geração de seções de choque para o primeiro núcleo do Reator Multipropósito Brasileiro, Relatório técnico: RMB-10100-RD-003.00.