ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR – ABEN
2019 International Nuclear Atlantic Conference - INAC 2019
Santos, SP, Brazil, October 21-25, 2019

Agência Brasileira do ISBN
ISBN 978-85-99141-08-3

VALIDATION OF THE RELAP5 CODE FOR THE SIMULATION OF THE SIPHON BREAK EFFECT IN POOL TYPE RESEARCH REACTORS

Antonio Belchior Junior[1], Humberto Vitor Soares[2] and Roberto Longo Freitas[3]

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

[2]Amazônia Azul Tecnologias de Defesa S.A. - AMAZUL
Av. Corifeu de Azevedo Marques, 1.847
05581-001 São Paulo, SP, Brazil
humberto.soares@amazul.gov.br

[3]Centro de Coordenação RMB – RMB/CNEN
Av. Professor Lineu Prestes 2242
05508-000 São Paulo, SP, Brazil
roberto.freitas@ipen.br

ABSTRACT

In an open pool type reactor, the pool water inventory should act as a heat sink to provide emergency reactor core cooling. In the Brazilian Multipurpose Reactor – RMB, to avoid the loss of pool water inventory, all the Core Cooling System (CCS) lines penetrate at the pool top, far above the reactor core level. However, as most of CCS equipment and lines are located below the reactor core level, in the case of a Loss of Coolant Accident (LOCA), a large amount of pool water could be lost drained by siphon effect. To avoid RMB research reactor core discovering in the case of a LOCA, siphon breakers, that allow CCS line air intake, are installed in the CCS lines in order to stop the reactor pool draining due to siphon effect. As siphon breakers are important passive safety devices, their effectiveness should be verified. Several previous numerical and experimental studies about siphon break effect were found in the literature. Some of them comment about the effectiveness of the siphon breakers based on their air intake area. Others state that one-dimensional thermo-hydraulic system codes such as RELAP5 code would fail when modeling the siphon break effect.

This work shows the RELAP5/MOD3.3 code capability in modeling the siphon break effect. A nodalization for RELAP5/MOD3.3 code of a Siphon Breaker Test Facility located at POSTECH University in Korea was developed. Experiments considering several siphon breakers device intake areas were simulated. A very good agreement between numerical and experimental results was obtained. As siphon breakers intake areas decrease, the siphon breaker effectiveness also decreases and more water is drained from the reactor pool. For smaller siphon breaker intake areas, RELAP5/MOD3.3 code showed conservative results, overestimating the reactor pool water losses.

1. INTRODUCTION

The Brazilian Nuclear Energy Commission (CNEN) is leading the project of the Brazilian Multipurpose Reactor (RMB) aimed to be projected, constructed, and operated to attend the present Brazilian needs for a multipurpose neutron source, which will be able to supply the radioisotope demand, carrying out material tests, scientific development, commercial, and medical applications with the use of neutron beams.

Currently, the RMB project is in detail engineering design phase, which is being done by the engineering companies INVAP (Argentina), AMAZUL (Brazil) and IPEN (Brazil). The RELAP5 code [1] has been used in the safety analysis of RMB reactor.

In a pool type research reactor, the reactor pool can act as a heat sink for the reactor core decay power. Heat can be transferred by natural circulation from the reactor core to the reactor pool. So, to keep the reactor core cooling, the reactor should be kept covered. In recent design of pool type research reactor, pool penetrations below reactor core top are avoided. Despite the piping-system penetrate the pool above the reactor pool level, if a pipe rupture occurs, it can lead to a loss of coolant accident (LOCA) since the coolant could be siphon out of the reactor pool until the pressure head between the inlet and outlet is removed or the siphon flow is interrupted. A siphon breaker mechanism can be adopted as a passive safety device to protect the reactor core avoiding the lack of cooling water in the fuel elements.

The thermal hydraulic system code RELAP5 was developed to best estimate transient simulation of light water power reactor systems during postulated accidents. Recent works have demonstrated that the code can be also used with good predictions for thermal hydraulic analysis of research reactors as it can be verified in the present literature [2], [3], [4], [5], [6], [7] and [8]. In previous works, the assessment and validation of thermal-hydraulic system code have been performed in order to investigate the applicability of RELAP5 code to evaluate safety margins of an MTR research reactor [9]. The application of RELAP5 code to research reactor has been already assessed [6], [10] and [11]. Furthermore, the latest's version of RELAP5 was made suitable for research reactor applications [12]. Although RELAP5 code has been successfully used in research reactors simulation, some work reported it is not suitable to simulate the siphon breaker actuation [13], [14] and [15].

Neill et al. in [13] developed a two-year project for siphon breaker studies. They intended to develop experimental facility and its RELAP5 code modeling. Even after one-year project extension, they were not able to obtain any useful results from a RELAP5 code model of the siphon system. Despite that, they produced and analyzed a very large set experimental result. Through their series of tests, they confirm that there are three separate modes of siphon breaker performance as they describe:

a) There is a zero-air entrainment mode in which the siphon breaker air accumulates as a large bubble at the top of the discharge line and through which the water flows as in a water-fall. The additional kinetic energy of the water required to increase its velocity through the air bubble and the potential energy of the water gained while falling through the air bubble may be completely dissipated at the base of the water fall. We believe the net effect of this energy loss will cause an increased siphon breaker air flow and hence break the siphon sooner than it would if such losses didn't occur.

b) There is a partial air entrainment mode in which a significant fraction of the siphon breaker air is entrained by the discharging water. The two-phase flow for this mode has two possibly different regimes: a bubbly flow characterized by relatively small air bubbles and a mini water-fall flow characterized by large bubbles which appear to move down the discharge line slower than the average water velocity. We did not see any cases where the large air bubbles moved up the discharge line against the downward water flow. The "friction" losses for these two two-phase flow regimes may be Significantly different. In any case, accumulating sufficient air within the discharge line to break the siphon is a slow process because so much air is entrained out the discharge.

c) Finally, there is a full air entrainment mode in which all the siphon breaker air is entrained by the discharging water. The two-phase flow regime is bubbly flow characterized by relatively small air bubbles; however, they saw large eddies of bubbly flow the which may be precursors to the formation of mini water-falls. Siphon breaker air is not accumulated in the discharge line while in this mode and the siphon will not break until after the flow slows enough for a transition to the partial air entrainment mode.

Chun et al. in [14] developed a RELAP5/MOD3.3 code simulation for a POSTECH Siphon Breaker Test Facility [16]. Their results were compared with the results of the CUPID code [17] by Park et al. in [15]. Their RELAP5/MOD3.3 code calculation showed a delayed siphon breaker effect and the calculated water level at the end of transient dropped more than 1.5 m below the experimental result. On the other hand, the CUPID results presented a better agreement. They concluded the 3-D phenomena of the siphon breaker device were not correctly captured by the RELAP5/MOD3.3 code 1-D models. Youn-Gyu et al. [18] presented a RELAP5 code simulation with a better agreement against POSTECH experimental results.

This work intends to verify the RELAP5/MOD3.3 code capability in modeling the siphon breaker mechanism. RELAP5/MOD3.3 code calculation of a Siphon Breaker Test Facility located at POSTECH University in Korea will be done. Several experiments considering different siphon breakers device intake areas and pipe rupture location will be simulated and compared against experimental results.

2. RELAP5/MOD3.3 CODE SIMULATION OF POSTECH SIPHON BREAKER EXPERIMENT

2.1. POSTECH Siphon Breaker test facility.

The POSTECH Siphon Breaker Test Facility [16] consists of an upper tank, a main drainage pipe, discharge valves and pipes, a lower tank and a siphon breaker line. A schematic diagram of the test facility is shown in Figure 1. The upper tank is 4.0 m depth, it has a square transversal section and about 60 m³ water capacity. The main drainage pipe,16 inches diameter, connects the bottom of the upper tank to two discharge lines. Each discharge line has an electrically operated butterfly valve and a flange where can be attached reducing pipes of 6, 8 or 10 inches diameter to vary the LOCA break area. The height differences between the entrance of the siphon breaker line and the pipe break locations are 11.58 m for LOCA break location A and 6.58 m for LOCA break location B. Inverted U-tube siphon breaker lines of diameters varying from 0.5 to 2.5 inches can be connected between the upper part of the inverted U-tube region of the main drainage pipe and the top of the upper. The entrance of siphon breaker line is located 3.35 m above from the bottom of the upper tank.

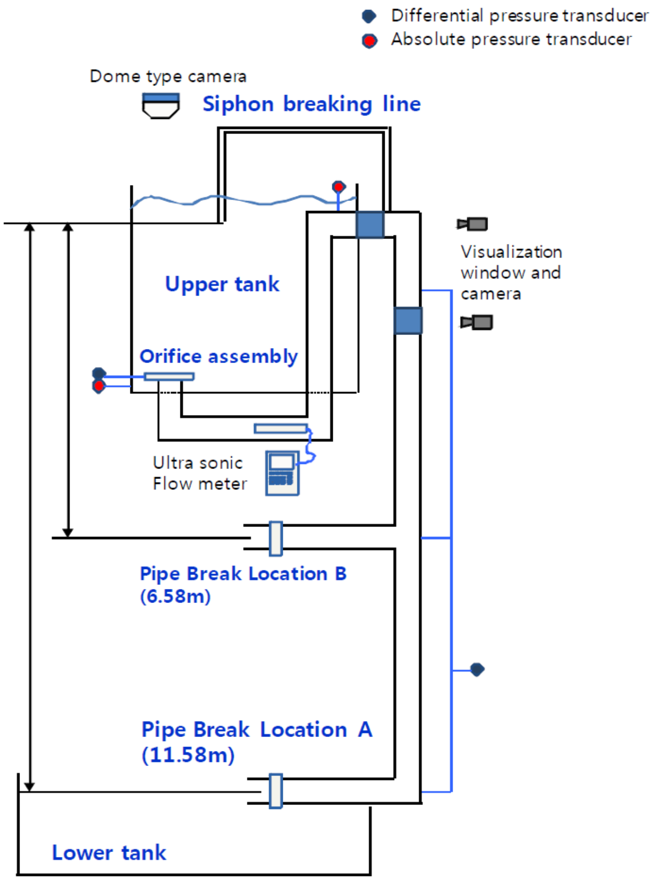

Figure 1: Schematic representation of POSTECH siphon breaker test facility [14].

2.2. RELAP5/RMB Model for POSTECH Siphon Breaker Test Facility

A RELAP5/Mod3.3 code model was developed in order to simulate the POSTECH Siphon Breaker Test Facility. A schematic diagram of this nodalization is presented in Figure 2. The upper tank is represented by the PIPE 200, the discharge line by the PIPE 300 and 420, the butterfly valves by the VALVE 350 and 430, the break pipes by the BRANCH 400 and 440. The siphon breaker line is represented by the PIPE 100 and is connected by the SNGLJUN at the 3rd volume of PIPE 200 (upper tank) and to 22nd volume of the PIPE 300 (discharging line). The orifice plate is represented at SNGLJUN 250 connecting the bottom of the upper tank to the entrance of the discharge line. The PIPE 600 represent the external environment (first 28 volumes) and the lower tank (last 4 volumes). The system pressure is sustained by the CNTRLVOL 500 that is connected by the SNGLJUN 550 at the entrance of PIPE 500.

The facility geometrical data were obtained from the literature [14], [15] [16], [19] and [20]. All the elevation changes are considered by the center line of the pipes and all the pressure drop coefficients (K-factor) are calculated based on the appendix A of [21]. Neither special control flag nor modelling tricks were applied in the nodalization.

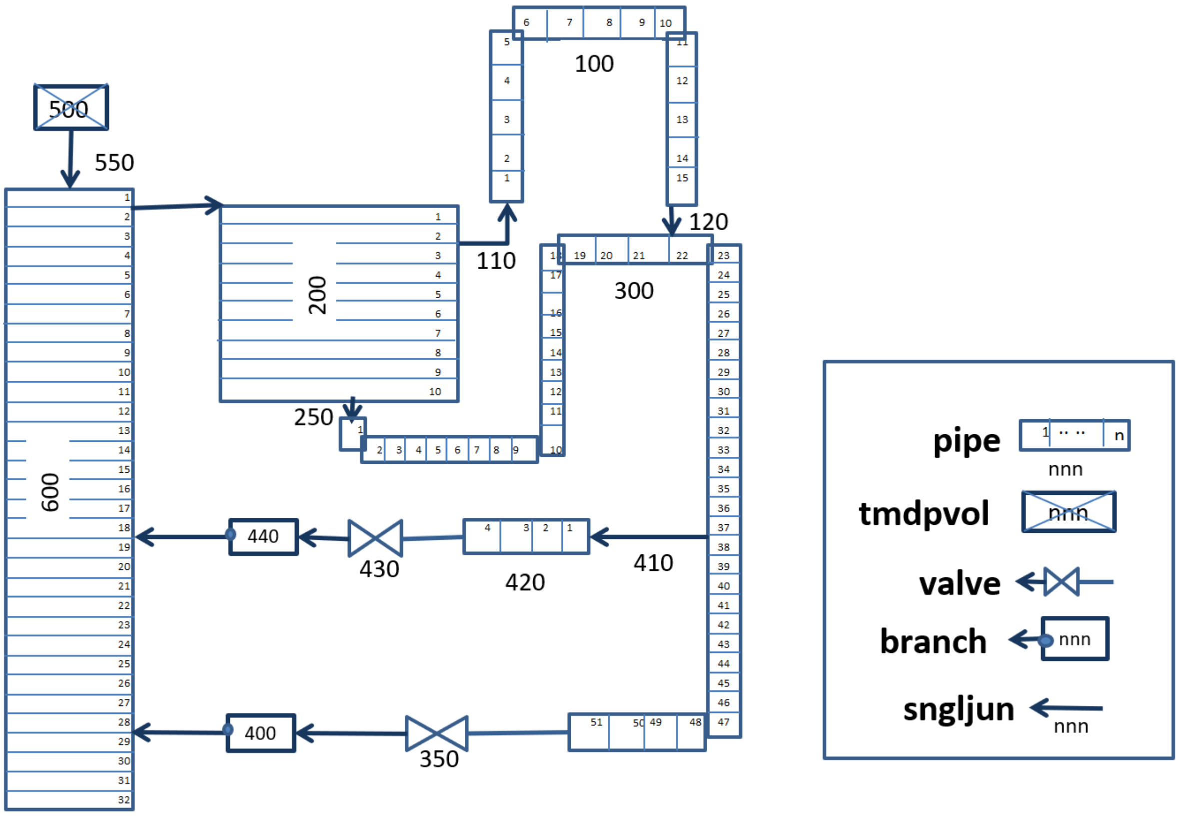

Figure 2: RELAP5/RMB nodalization to simulate POSTECH Experiment.

2.3. RELAP5/RMB Simulation Results

The complete set of experiments presented in [15] were simulated. They combine a 10 inches rupture pipe in two LOCA position (LOCA A and LOCA B presented in Figure 1) and five siphon breaker line diameters (0.5, 1.0, 1.5, 2.0 and 2.5 inches).

The first calculation considers a LOCA in the lowest position (LOCA A) and a 2.5 inches siphon breaker line diameter for which the time behavior of the water tank level during the experiment was available in the literature. For this condition, the RELAP5 code calculation developed by Chun et al. in [14] are compared with the CUPID [17] results by Park et al. in [15]. Their RELAP5 code calculation showed a delayed siphon breaker effect and the calculated water level at the end of transient dropped more than 1.5 m below the experimental result. On the other hand, the CUPID results presented a better agreement. Youn-Gyu et al. presented a RELAP5 code simulation in [18] with a better agreement against POSTECH experimental results.

The Figure 3 shows a comparison of the results presented in [15] against the RELAP5/Mod3.3 code model developed in this work, called RELAP5/RMB. The one-dimensional RELAP5/RMB results showed a perfect agreement against the POSTECH experimental result, even much better than the 3-D CUPID code results.

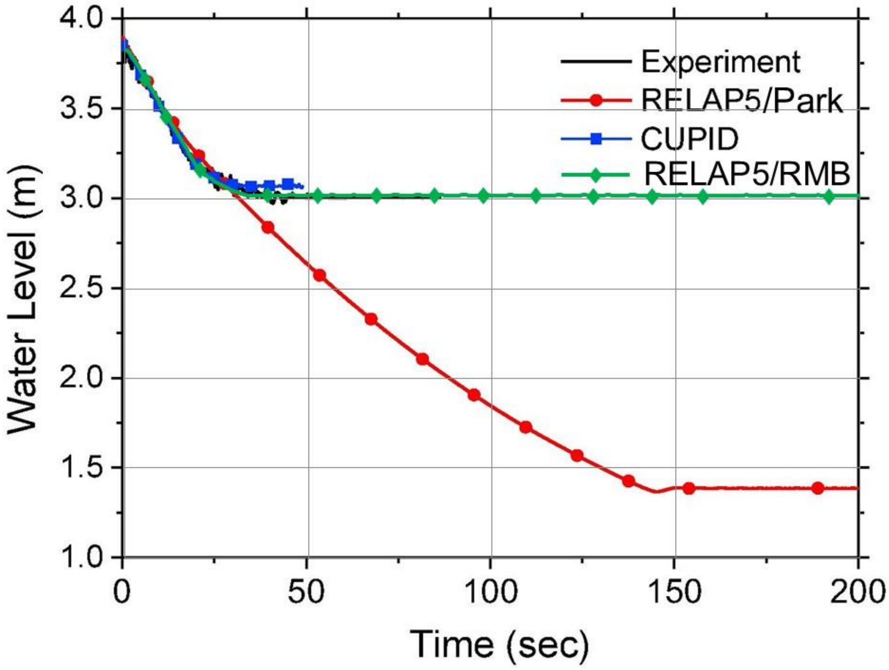

Figure 3: Comparison of RELAP5/RMB results against POSTECH experimental and numerical results presented in [15].

Due to RELAP5 code observed discrepancies, Chun et al. [14] and Park et al. [15] conclude that RELAP5 was not able to capture the complex 3D phenomena that occurs at siphon break line and its connection to the discharge line. However, looking at the RELAP5/MOD3.3 code nodalization presented in [14], probably the main source for their observed discrepancies was the nodalization of the upper tank. It seems they use only one control volume to represent the region below the siphon breaker line connection point. So, the entrance of siphon breaker line was connected to a 3.35 m height control volume larger than 50 m^3. As RELAP5 code default calculation options consider the void fraction for a junction connecting two control volumes the same as that of the donor control volume, water will continue being entrapped to siphon breaker line in RELAP5 code calculation even after the entrance of this line has been exposed to the air.

To verify this hypothesis and to show that the RELAP5/Mod3.3 is not immune to user effects, the RELAP5/RMB nodalization was modified in one detail only: the last eight volume of PIPE 200 (Figure 2) where lumped to only one. The Figure 4 compares the original RELAP5/RMB calculated upper tank level and void fraction at the siphon break line entrance junction against the modified version. While in the original RELAP5/RMB, void fraction at the entrance junction of siphon break line promptly increases to 1 and pure air enters the siphon breaker line when its entrance is exposed to the air, in the modified version that void fraction increases slowly, associated directly with the decrease of upper tank level. So, in the modified version, the upper tank water level presented the same behavior as the observed by Chun et al. [14] and Park et al. [15]. Since not enough air entered the siphon breaker line, the siphon breaker actuation failed and the tank level dropped until 0.4 m.

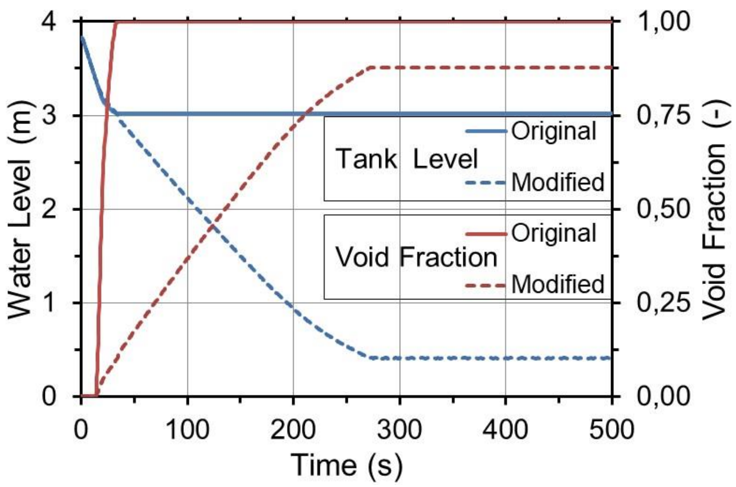

Figure 4: Comparison of water tank level and siphon breaker line entrance void fraction for original RELAP5/RMB against a modified version inducing siphon breaker failure.

The results of RELAP5/MOD3.3 code simulation of the behavior of the upper tank level for the entire set of considered experiments are presented in Figure 5 for the LOCA at the lowest position and in Figure 6 for a LOCA at the intermediate position. Unfortunately, the experimental time behavior was not available for comparison. The final upper tank level for each experiment compared against the experimental results obtained from [15] are presented in Table 1. The RELAP 5 results presented a perfect agreement for the cases that the siphon break line diameters is large enough to inject an amount of air that breaks the siphon immediately, as in the first siphon break mode mentioned in introduction section as a conclusion of Neil et al. work [13]. Decreasing the siphon break line diameter, one of the other two siphon break mode are activated. As RELAP5/MOD3.3 code seems to overestimate the air entrainment, it takes longer to accumulate enough air to end the siphon effect, so the water discharged was overestimated.

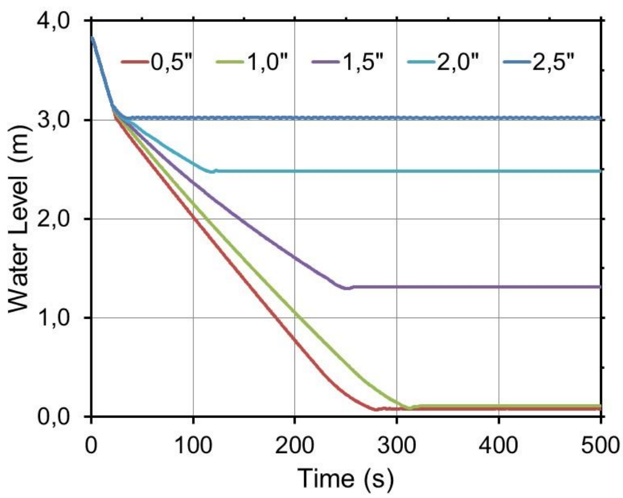

Figure 5: RELAP5/RMB results for several siphon breakers line diameters for LOCA at lowest position.

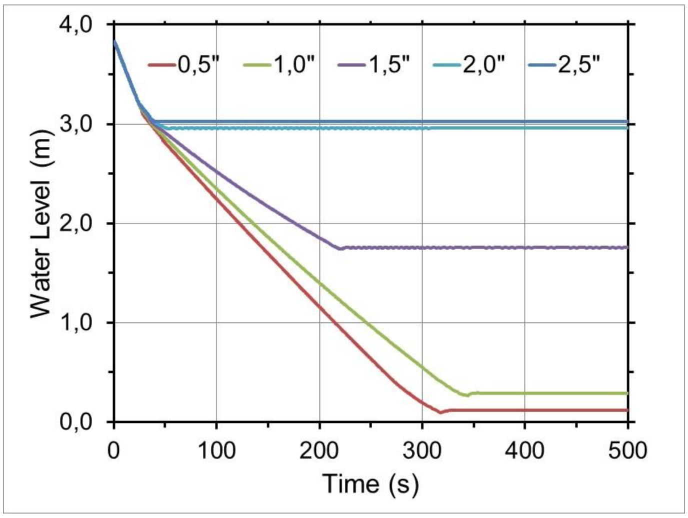

Figure 6: RELAP5/RMB results for several siphon breakers line diameters for LOCA at intermediate position.

Table 1: Final tank level for several siphon break line diameter and break position.

Siphon break line diameter	**Final Tank Level (m)**			
	LOCA A		**LOCA B**	
	Experimental	**RELAP5/RMB**	**Experimental**	**RELAP5/RMB**
69,0 mm (2,5”)	3,02	3,02	3,14	3,03
53,2 mm (2,0”)	2,56	2,48	3,05	2,96
43,8 mm (1,5”)	1,89	1,31	2,83	1,75
27,9 mm (1,0”)	Não	0,11	1,30	0,29
17,1 mm (0,5”)	Não	0,08	Não	0,12

3. CONCLUSIONS

The RELAP5/MOD3.3 code capability in modeling the siphon break effect was verified. For this, a RELAP5/MOD3.3 code nodalization of a POSTECH Siphon Breaker Test Facility was developed and a set of experiments considering several siphon breakers device intake areas and LOCA positions were simulated. A very good agreement between numerical and experimental results was obtained for large intake areas. As siphon breakers intake areas decrease, the siphon breaker effectiveness also decreases and more water is drained from the reactor pool. For smaller siphon breaker intake areas, when compared against the experimental results, RELAP5/MOD3.3 code overestimated the reactor pool water losses. The RELAP5/MOD3.3 code presented conservative result.

It is important to note that from the results obtained when comparing the RELAP5/Mod3.3 code simulation with the POSTECH experiment, the RELAP5/Mod3.3 code is able to simulate the phenomena involved in the performance of siphon breaking devices in an APRP. with a direct application to RMB safety analysis studies [22].

ACKNOWLEDGMENTS

The authors would like to thank IPEN/CNEN-SP and AMAZUL in acknowledgement of their structures and willing to push forward science and nuclear technology in Brazil.

REFERENCES

1. US NRC, UNITED STATES NUCLEAR REGULATORY COMMISSION. RELAP5/MOD3.3 Code Manuals. **Idaho National Engineering Laboratory**, NUREG/CR-5535, 2001.
2. A. R. ANTARIKSAWAN, M. Q. HUDA, T. LIU, J. ZMITKOVA, C. M. ALLISON, AND J. K. HOHORST. Validation of RELAP/SCAPSIM/MOD3. 4 for research reactor applications. **Proceedings of the 13th International Conference on Nuclear Engineering**, Beijing, China, 2005.
3. DAVIS, C. B. Applicability of RELAP5/MOD3. 2 to research reactors. **Proceedings of the IAEA Regional Training Workshop on Safety Analysis Methodology and Computer Code Utilization, KINS**, Daejeon, Republic of Korea, 2002.
4. B. DIMARO, F. PIERRO, A. BOUSBIA SALAH, AND F. D’AURIA. Analysis of a pump trip in a typical research reactor by RELAP5/MOD 3.3. **Proceedings of the International Congress on Advances in Nuclear Power Plants (ICAPP ’03)**, Cordoba, Spain, 2003.
5. A. L. COSTA, P. A. L. REIS, C. PEREIRA, M. A. F. VELOSO, A. Z. MESQUITA, AND H. V. SOARES. Thermal hydraulic analysis of the IPR-R1 TRIGA research reactor using a RELAP5 model. **Nuclear Engineering and Design**, vol. 240, no. 6, p. 1487–1494, 2010.
6. T. HAMIDOUCHE, A. BOUSBIA-SALAH, M. ADORNI, AND F. D'AURIA. Dynamic calculations of the IAEA safety MTR research reactor Benchmark problem using RELAP5/3.2 code. **Annals of Nuclear Energy**, vol. 31, no. 12, p. 1385–1402, 2004.
7. A. KHEDR, M. ADORNI, ANDF. D’AURIA. The effect of code user and boundary conditions on RELAP calculations of MTR research reactor transient scenarios. **Nuclear**

Technology and Radiation Protection, vol. 1, p. 16-22, 2005.

8. P. A. L. REIS, A. L. COSTA, C. PEREIRA ET AL. Assessment of a RELAP5 model for the IPR-R1 TRIGA research reactor. **Annals of Nuclear Energy**, vol. 37, no. 10, p. 1341–1350, 2010.
9. T. HAMIDOUCHE AND A. BOUSBIA-SALAH. RELAP5/3.2 assessment against low pressure onset of flow instability in parallel heated channels. **Annals of Nuclear Energy**, vol. 33, no. 6, p. 510–520, 2006.
10. W. L. WOODRUFF, N. A. HANAN, R. S. SMITH, AND J. E. MATOS. A comparison of the PARET/ANL and RELAP5/MOD3. 3 codes for the analysis of IAEA benchmark transients. **Proceedings of the International Meeting on Reduced Enrichment for Research and Test Reactors**, Seoul, Republic of Korea, 1996.
11. A. HEDAYAT, H. DAVILU, AND J. JAFARI. Loss of coolant accident analyses on Tehran research reactor by RELAP5/MOD3.2 code. **Progress in Nuclear Energy**, vol. 49, no. 7, p. 511–528, 2007.
12. C. ALLISON, J. K. HOHORST, A. ANTARIKSAWAN ET AL. Validation of RELAP/SCDAPSIM/MOD3.4 for research reactor applications. **Proceeding of the 13th International Conference on Nuclear Engineering (ICONE 05)**, China, 2005.
13. NEILL, D. T.; STEPHENS, A. G. **Siphon Breaker Design Requirements - Final Report**. USA DOE. [S.l.]. 1993. (DE-FG07-88ER12820).
14. CHUN, J. H. et al. RELAP5/Mod3.3 Simulation of Siphon Break Experiments. **The 15th International Topical Meeting on Nuclear Reactor Thermalhydraulics, NURETH-15**, Pisa, 12-15 May 2013. 1-11.
15. PARK, I. K.; YOON, H. Y.; BEOMPARK, H. Numerical approach to siphon break phenomena in a research reactor pool using the CUPID code. **Nuclear Engineering and Design**, v. 326, p. 133-142, January 2018.
16. LEE, K. Y. et al. Experimental and Analitic Studies on Siphon Breakers in a Research Reactors. **European Research Reactor Conference 2012** , Prague, Czech Republic, 18-22 March 2012.
17. JEONG, J. J. et al. The CUPID code development and assessment strategy. **Nucl. Eng. Technol.**, v. 42, p. 636,655, june 2010.
18. YOUN-GYU, J.; JANG, D.; PARK, S. SPACE3.0 and RELAP5/MOD3.3 Simulations of Siphon Break Experiments. **Transactions of the Korean Nuclear Society Autumn Meeting**, Gyeongju, Korea, 26-27 October 2017.
19. SEO, K. et al. Experimental and numerical study for a siphon breaker design of a research reactor. **Annals of Nuclear Energy**, v. 50, p. 94-102, 2012.
20. MATOZINHOS, C. F.; SANTOS, A. A. C. D. Two-phase CFD simulation of research reactor siphon breakers: A verification, validation and applicability study. **Nuclear Engineering and Design**, v. 326, p. 7-16, January 2018.
21. CRANE CO. **Flow of Fluids Through Valves, Fittings and Pipes**. Crane Co. New York, p. 133. 1982. (Technical paper No. 410M).
22. SOARES, H. V.; BELCHIOR JR, A.; FREITAS, R. L. RELAP5 Modeling of a Siphon Break Effect on the Brazilian Multipurpose Reactor. **2019 International Nuclear Atlantic Conference - INAC 2019**, Santos, SP, Brazil, 21-25 October 2019.