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SIMULATION OF THE FIRST STEP OF THE COUPLING OF THE PARCS/RELAP5 CODES TO ANGRA 2 FACILITY

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ABSTRACT

Since the Three Mile Island (1979) and Chernobyl (1986) accidents, the International Agency of Energy Atomic (IAEA) has worked with the authorities of other countries that use nuclear power plants in order to guarantee the safe of those facilities. The utilities have simulated design basic accidents to verify the integrity of the nuclear power plant to these events. However, after Fukushima accident in Japan (2011), the people have felt insecure and been afraid in relation to nuclear power plants. Today, the international and national organizations, such as the International Agency of Energy Atomic (IAEA) and *Comissão Nacional de Energia Nuclear* (CNEN), respectively, have worked very hard to prevent some accidents and transients in nuclear power plants in order to ensure the security of the general population. In case of accidents, as the Rod Ejection Accident (REA), it is very important to do the coupling between neutronic and thermal hydraulic areas of nuclear reactors. To solve this type of problem there is the coupling between PARCS/RELAP5 codes. However, to perform this analysis it is necessary to simulate three steps. The first step is simulating the steady state of one nuclear power plant by using RELAP5 code. The second step is to run the steady state of this reactor using the coupling PARCS/RELAP5, and the final step is simulating the REA of this facility with PARCS/RELAP5 coupling. The aim of this work is to show the results of the first step of this analysis, i.e., by means of simulation the steady state of Angra 2 nuclear power plant using RELAP5 version 3.3. In this case, the modeling from the core was more detailed than in the original version developed some years ago for Angra 2. The results obtained in this work were satisfactory.

1. INTRODUCTION

Doe to the nuclear accidents occurred in the world, such as, Three Mile Island (1979) [1], Chernobyl (1986)[2], and Fukushima in Japan (2011) [3] the people have felt insecure and been afraid in relation to nuclear power plants. Today, the international and national organizations, such as the International Agency of Energy Atomic (IAEA) and *Comissão Nacional de Energia Nuclear* (CNEN), respectively, have worked very hard to prevent some accidents and transients in nuclear power plants, in order to ensure the security of the general population.

The Nuclear Power Plants have operated within the IAEA safety criteria. Some accidents and transients have been studied as the Rod Ejection Accident (REA).

The REA is defined as a result due to mechanical failure (rupture) of the Rod Cluster Control Assembly (RCCA) and its drive is located on the top of the reactor vessel. In this case, a bounding minimum ejection time of 0.1s, the REA leads to a fast core transient. The ejection of RCCA produce an instantaneous positive reactivity insertion to the reactor core and results in increasing neutron flux and fission power. In this study the vessel rupture is not considered.

A REA is investigated by means of the coupling neutronic/thermal-hydraulics – PARCS [4]/RELAP5 [5] codes.

The aim of this work is to show the results of the first step of the REA, i.e., by means of simulation the steady state of the Angra 2 nuclear power plant by using RELAP5 version 3.3. In this case, the modeling of the core was more detailed than in the original version developed some years ago for Angra 2 [6]. This work is part of the PARCS/RELAP5 codes coupling. The reactor Angra 2 was chosen for this simulation, because it had its modeling tested and compared to other accidents described in the Final Safety Analysis Report (FSAR) [7].

2. METODOLOGY

In this study modeling the facility is required, i.e., the nodalization of the core, of the primary circuit, of the pumps, of the pressurizer, and the of the steam generators (primary and the secondary sides). The first step of the PARCS/RELAP5 coupling is to simulate the steady state of the nuclear power plant – Angra 2 by using RELAP5/mod 3.3 code. The second step consists of modeling the core of the facility to the PARCS according to the RELAP5 nodalization, and then simulate the permanent regime using both codes. Finally, the third step is to simulate the accident proposed with the two programs. Figure 1 shows this procedure, i.e., the neutronic/thermal-hydraulics, PARCS/RELAP5 coupling.

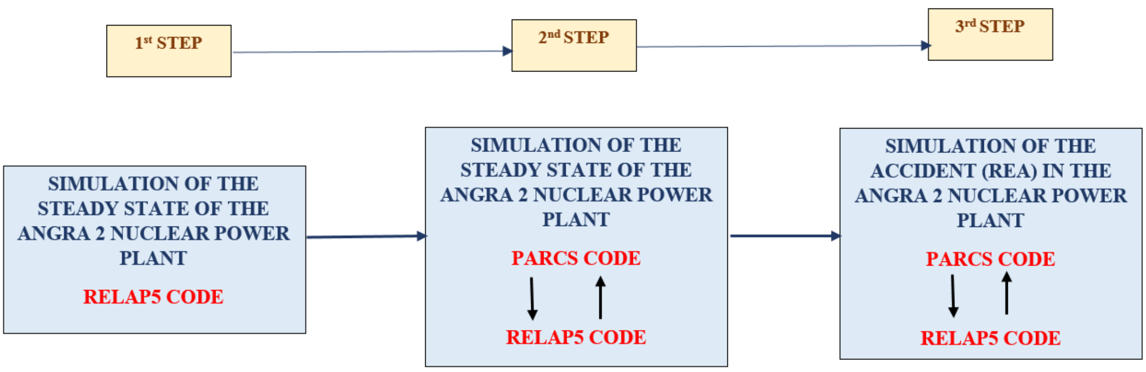

Figure 1: The three steps of the neutronic/thermal-hydraulic coupling.

In this first phase, described in Figure 1, the steady state of the Angra 2 was simulated by using RELAP5, with input file based on the multipurpose modeling developed in the work performed by the Technical Cooperation among *Instituto de Pesquisas Energética e Nucleares* (IPEN), *Centro de Desenvolvimento Tecnológico Nuclear* (CDTN), and *Comissão Nacional de Energia Nuclear* (CNEN) [6].

2.1. Computational Programs

The following programs will be used in the complete analysis of the PARCS and RELAP5/mod3.3 codes coupling. A brief summary of these codes is given below.

The RELAP5 was developed by the Idaho National Laboratory. This code was originally designed for the analysis of thermal hydraulic transients in Pressurized Water Reactors (PWR). The RELAP5 can model the primary and secondary cooling systems of experimental facilities and of nuclear reactors with geometric details. The program uses the non-homogeneous non-equilibrium two-fluid model, and considers the conservation equations of mass, momentum and energy for the liquid and gas phases. One-dimensional model is used to treat the fluid flow and the heat conduction in the structures; however, in some special cases such as the cross flow in the reactor core and the rewetting region in flooding model, the two-dimensional model is used [5].

The program PARCS is a simulator engine core in three-dimensional (3D), which solves the steady state and transient (such as rods, boron ejection, etc.), multi-group neutron diffusion and transport equations in non-orthogonal and orthogonal geometry. The program has the possibility of the coupling with RELAP5 code using the interface to Parallel Virtual Machine (PVM), which provides temperature and mass flow information for the PARCS during transient calculations, through the generation of the cross sections in few groups of energy. The PARCS is available as a standalone code to perform calculations that do not require coupling. A separate module, GenPMAXS, is used to generate the cross sections using TRITON, HELIOS or CASMO codes to the PMAXS format that can be read by the PARCS. The main features of the PARCS include the ability to perform calculations of eigenvalue, of transients (kinetic), of Xenon transient, of decay heat, and neutronic calculations for light water and heavy water reactors [4].

However, in this work only the first step will be presented, which is the steady state simulation of the Angra 2 using RELAP5 code.

2.2. Angra 2 Nodalization

The Angra 2 is a reactor of the type Pressurized Water Reactor (PWR), designed by Siemens/KWU with four circuits of pressurized water cooling, generating 3,765 MW of thermal power [7]. This reactor has a vessel, where there are nuclear fuel assemblies, as well as four cooling pumps, four steam generators and a pressurizer.

There is an Emergency Core Coolant System (ECCS) that consists of 8 lines that inject water in the hot and cold legs: 4 pumps of high-pressure injection, 4 pumps from the system of residual heat removal, and 4 borated water tanks.

Figure 2 shows the detailed of the modeling of the Angra 2 vessel; however, in this case, the modeling of the core was more detailed. It was divided into 19 axial meshes, with 15 of them being the active part of the core and the other four are non-active. The dimensions for this nodaliztion were equal to the core of ANGRA 2 Simulator.

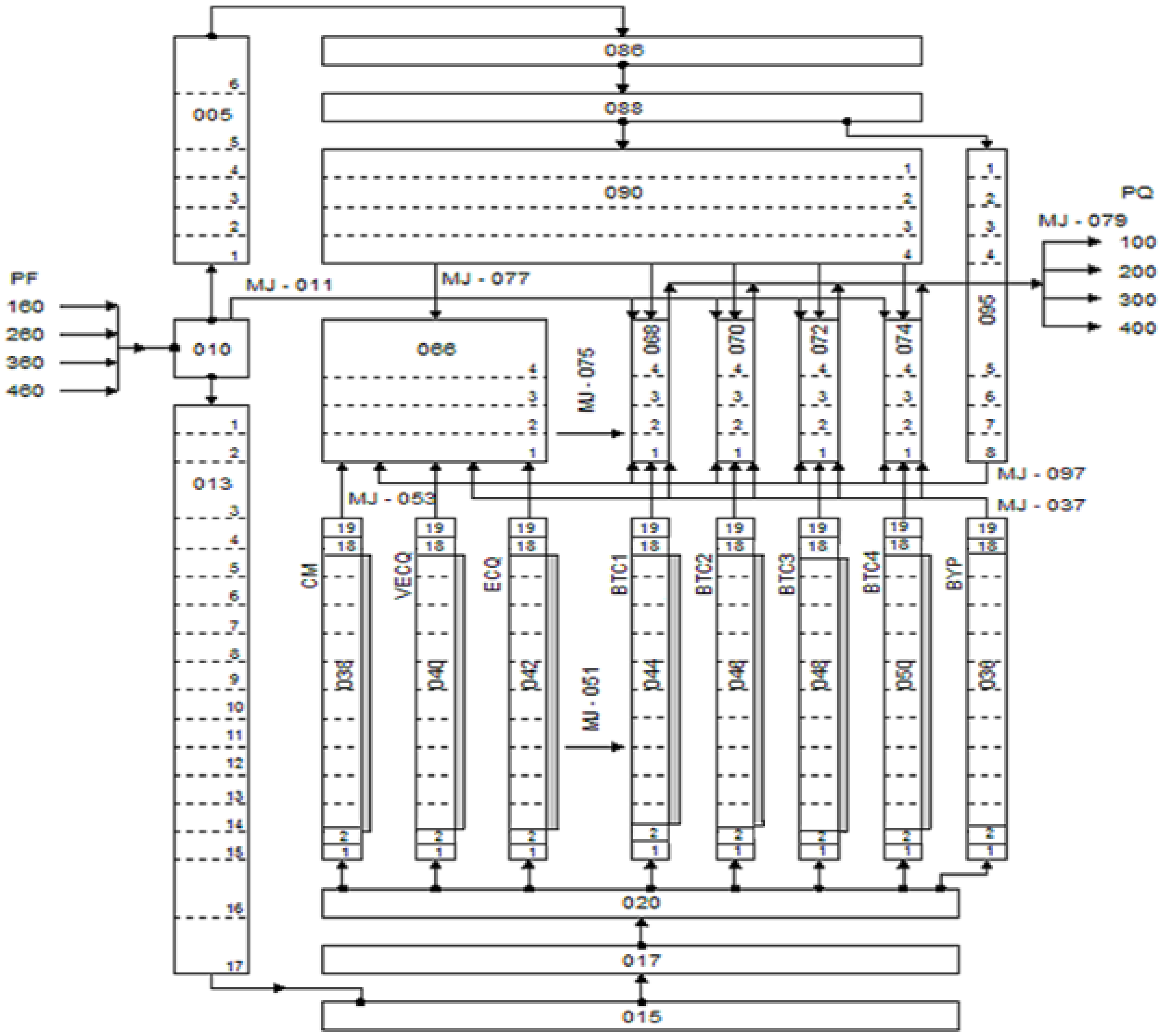

Figure 2: Vessel nodalization for RELAP5 code.

Figure 3 shows the core configuration of Angra 2 (28 assemblies with 248 fuel rods and 56 assemblies with 244 fuel rods each one, and 896-fuel poison rods). Figure 4 shows the location of the control rods (total of 2966 rods).

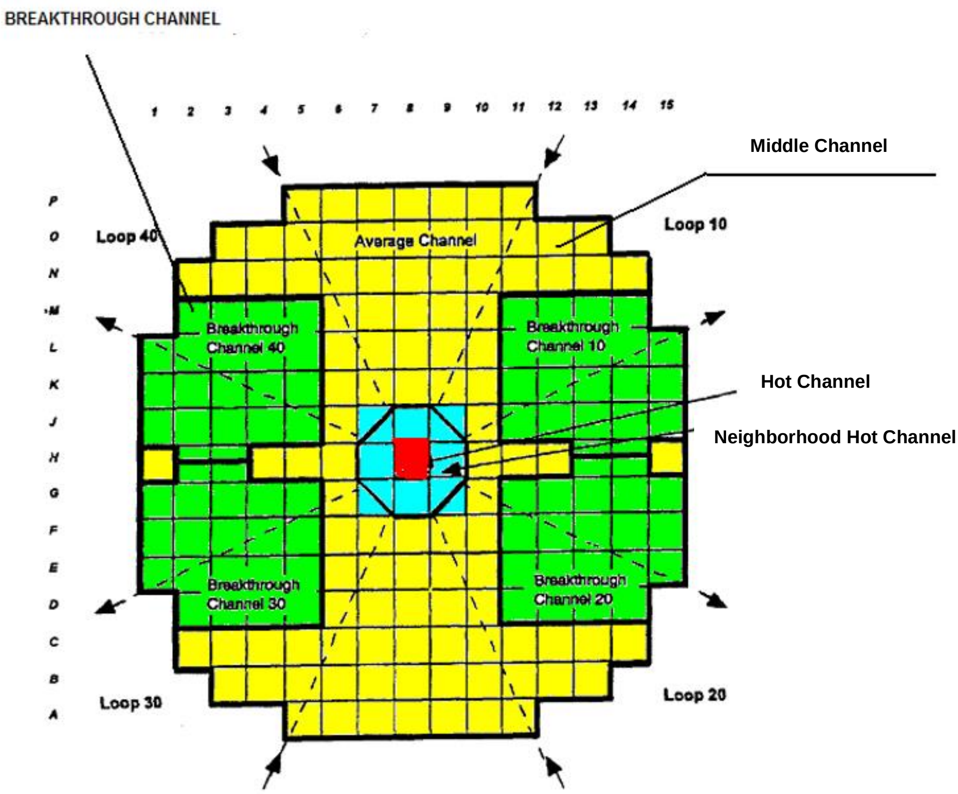

Figure 3: Distribution of the fuel rods in the Angra 2 core.

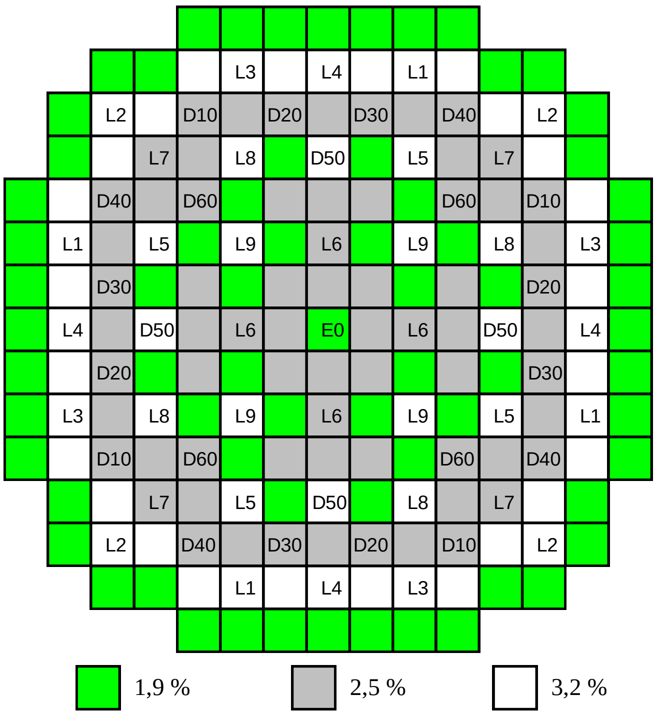

Figure 4: Radial location of the control rods.

The core is represented by heat exchange structures (active and non-active parts of the core). The component number 1042 represents the Hot Channel (HC), the component number 1040 represents the Neighborhood Hot Channel (NHC) and the component number 1038 represents the Middle Channel (MC). In the HC, there are 1234 fuel rods. In the NHC, there are eight fuel elements with 236 fuel rods each one. In the MC, there are 104 fuel elements with 236 fuel rods each one. The remaining fuel elements are in the Breakthrough Channel (BC 1, 2, 3 and 4) with 20 fuel elements with 236 rods each one (Total 45546 fuel rods). The core is divided into 19 axial control volumes, being 15 of the active part of the core and the other four are non-active.

In this paper the first step of the PARCS/RELAP5 coupling is presented, i. e. , the steady-state of the proposed nodalization of Angra 2 is simulated using RELAP5 code, according to Fig. 1.

3. RESULTS

In this work it was necessary to simulate around 6,000 seconds to establish the steady state, because several variables were initialized (Fig. 5 to 12)

Figure 5 shows the pressure in primary and secondary circuits. Figure 6 demonstrates the pressure in the core. In both cases the permanent regime using the RELAP5 code was reached.

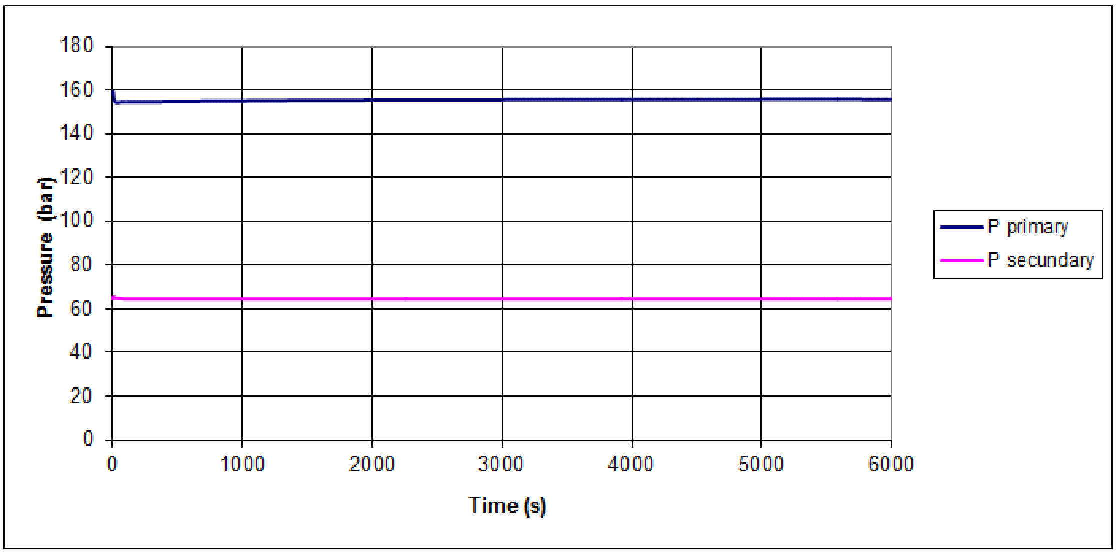

Figure 5: Pressure in primary and secondary circuits (RELAP5).

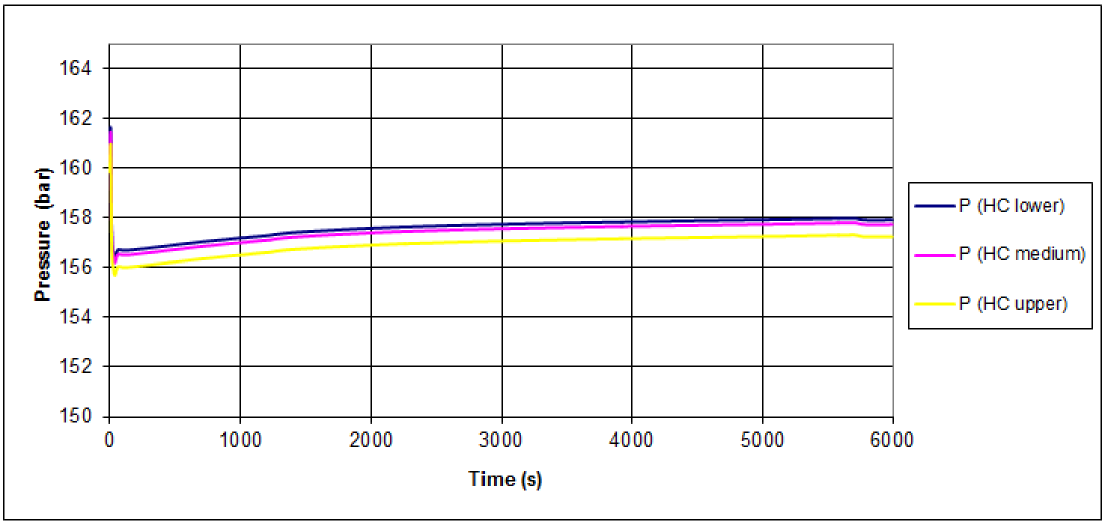

Figure 6: Pressure in the hot channel of the core (RELAP5).

The temperatures of the coolant in the hot channel of the core reached steady state as shown in Fig. 7. The temperature in the core was around 293°C in the inlet and the 345°C in the outlet, with a variation of core temperature around 40°C.

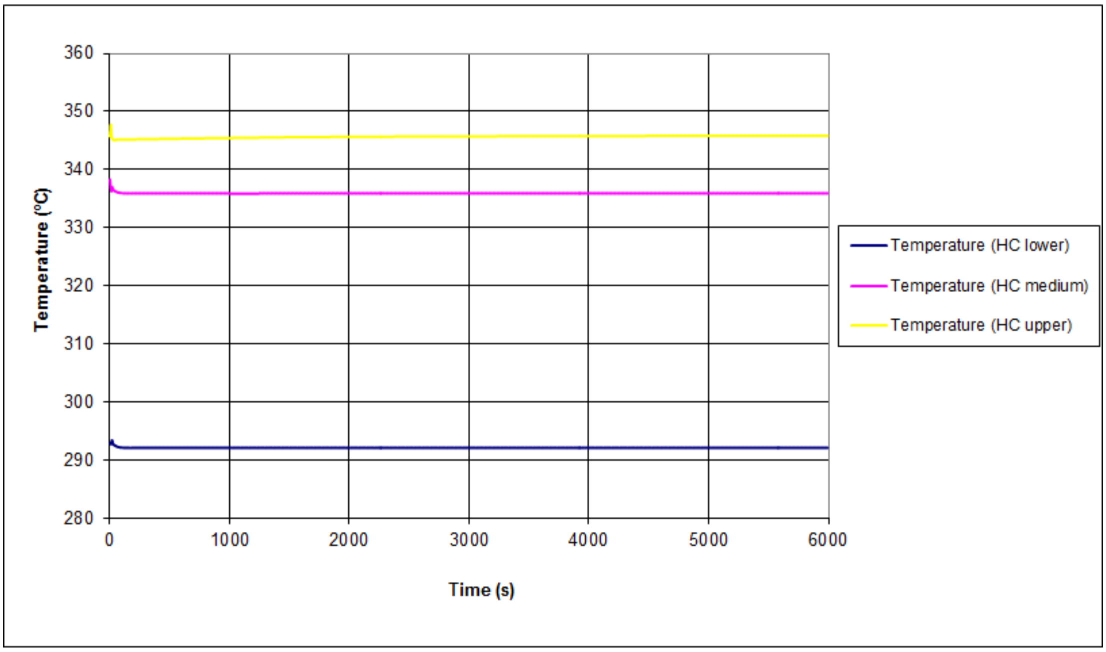

Figure 7: Coolant temperature in the hot channel of the core (RELAP5).

Figure 8 shows the maximum temperature reached by the cladding of the fuel rods, that is 358ºC and the minimum is 348°C.

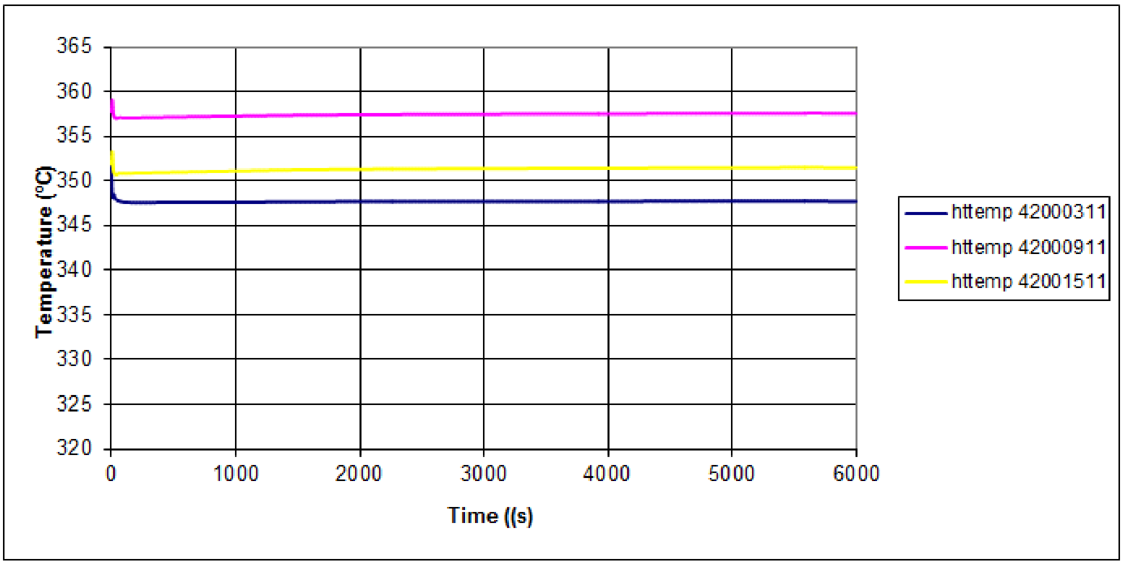

Figure 8: Cladding temperature in the hot channel of the core (RELAP5).

The mass flow in the hot leg and cold leg of the primary circuit is identical, as shown in Fig. 9.

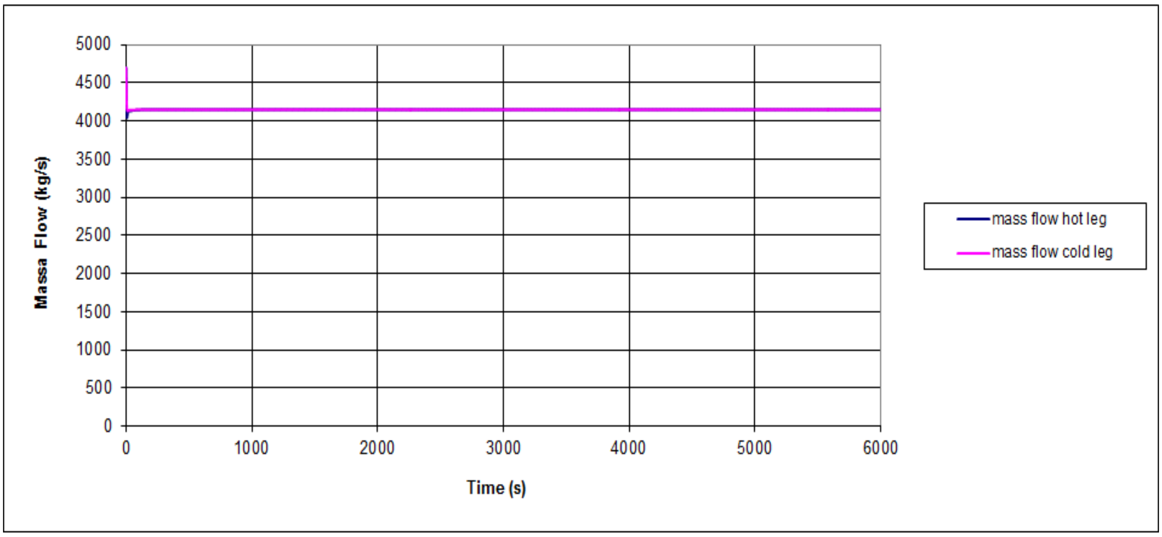

Figure 9: Mass flow in the cold and hot legs in the primary circuit (RELAP5).

Figure 10 shows the total power in the nuclear power plant in the steady state.

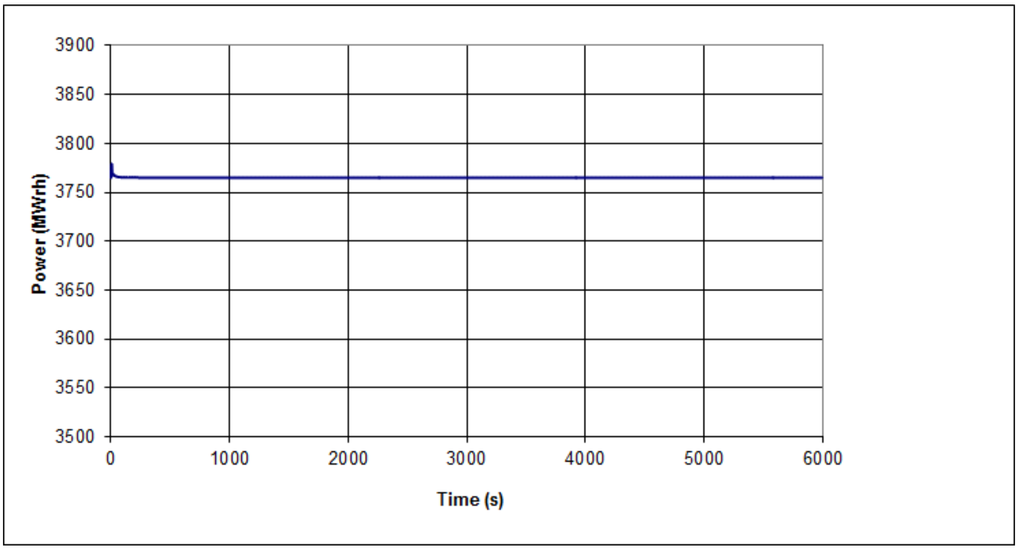

Figure 10: Total power of the Angra 2 (RELAP5).

Figure 11 presents the pressure in the hot leg and the pressurizer, which reaches the permanent regime after 4,000s of steady state simulation with RELAP5.

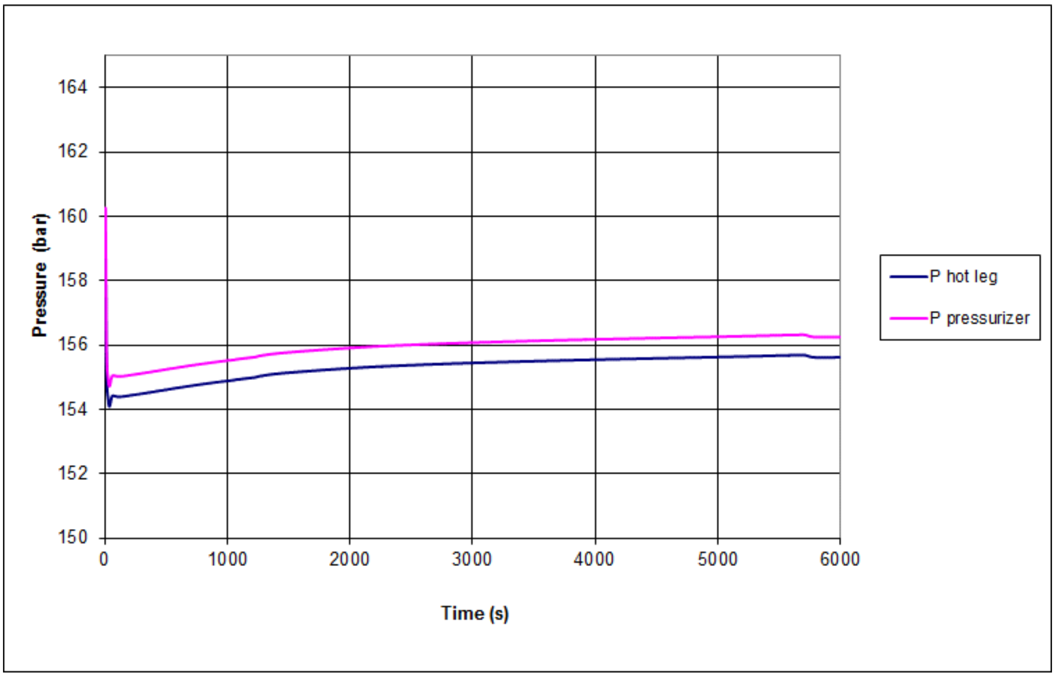

Figure 11: Pressure in hot leg and pressurizer (RELAP5).

Figure 12 shows the behavior of the mass flow rates: feed water and the steam from Steam Generator (SG), where the water entering to remove heat from the SG is not fully transformed to dry steam, because part of the steam returns to the system. Therefore, the results were satisfactory during the simulation of the permanent regime with RELAP5.

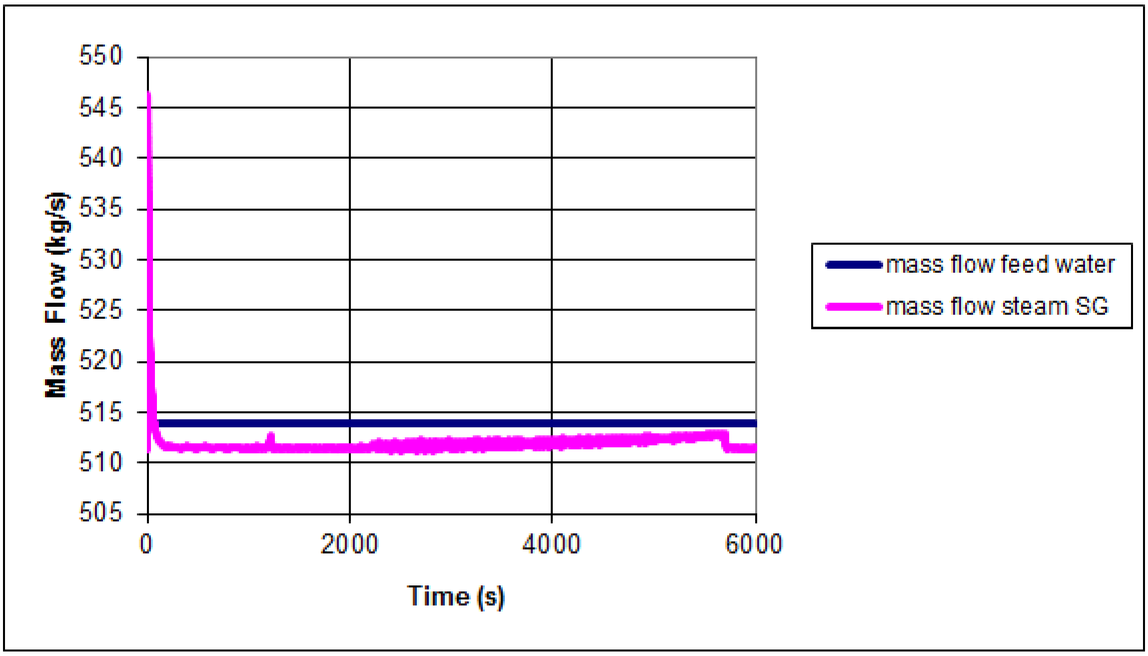

Figure 12: Mass flow from the feed water and steam from SG (RELAP5).

4. CONCLUSIONS

The steady state for the proposed nodalization for RELAP5 was successful. The first step of the coupling was completed, as shown in Fig. 1. The next steps consist of simulating the steady state and the REA with the PARCS/RELAP5 coupling.

ACKNOWLEDGMENTS

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REFERENCES

1. G.R. Corey. “A Brief Review of the Accident at Three Mile Island”**,** *IAEA BULLETIN***, V.21. NO.5**, http://www.iaea.org/publication/magazines/bulletin/bull215/21502795459.pdf (2015).
2. “Chernobyl’s Legal CY: Health Environmental and Socio-Economic Impacts and Recommendations to the Governments of Belarus”, the Russian Federation and Ukraine IAEA. Vienna (2003-2005).

3. R. Gauntt et al, “Fukushima Daiichi Accident Study” SANDIA REPORT SAND2012-6173 (2012).
4. T. Downar, Y. Xu and V. Seker ; “PARCS v3.0 - U.S. NRC Core Neutronics Simulator - USER MANUAL”, Department of Nuclear Engineering and Radiological Sciences, University of Michigan (2010).
5. “The RELAP5 Development Team, RELAP5/MOD3 Code Manual NUREG/CR-5535”, Idaho National Engineering Laboratory, USA (1995).
6. R. C. Borges, A. A. Madeira, L. C. M. Pereira, E. T. Palmieri, C. V. G. Azevedo, N. S. Lapa, G. Sabundjian e D. A. Andrade, “Simulação de Angra 2 com o código RELAP5/MOD3.2gamma”, *Sessão Técnica Especial*, *XIII Encontro Nacional de Física de Reatores e Termo-hidráulica*, Santos, SP, Brasil, 11-16 de agosto (2002).
7. ELETRONUCLEAR S. A, “Final Safety Analysis Report – Central Nuclear Almirante Álvaro Alberto – Unit 2”, *Doc: MA/2-0809.2/060000 -Rev. 3*, Abril (2000).