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COMPARISON BETWEEN RELAP5 VERSIONS FOR A TWO-PHASE NATURAL CIRCULATION ANALYSIS

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ABSTRACT

RELAP5 is one of the most used numerical tools to predict thermal-hydraulic and neutronic phenomena in nuclear reactors. RELAP5-3D is the latest version of this software family, but RELAP5-mod3 is still widely used in Brazilian research institutes and it is also used as benchmark for several nuclear applications. Among these applications, the use of passive heat transfer mechanisms, such as natural circulation, has drawn attention of several studies, especially after the Fukushima-Daiichi accident. Considering this aforementioned aspect, this study proposes a comparison of RELAP5-3D and RELAP5-mod3 versions, focusing on a two-phase natural circulation loop. For comparison purposes, an experimental data set is part of the analysis. Results showed that during the single-phase regime, the temperature difference between versions is negligible. However, when the two-phase flow regime takes place, different wavelengths and amplitudes of flow instabilities were obtained for each version. When compared to the experimental data set, the RELAP5-3D version provided the best prediction results.

1. INTRODUCTION

The RELAP5 computer code, which stands for Reactor Excursion and Leak Analysis Program, is one of the main analysis tools to perform thermo-hydraulics and neutronics simulations of nuclear reactors, piping flow, flow of coolant through rocket engines and others applications. In the case of nuclear power plants, generally, the main objective of the analysis is to calculate pressures, temperatures, flow, mass inventories, reactivities and power during reactivity events or loss of coolant accidents. RELAP-3D [1] is the latest version of this software family, but RELAP5-mod3 [2] is still widely used in Brazilian research institutes.

Natural circulation has been the focus of intense study by the nuclear community for use in passive safety systems, especially after the Fukushima-Daishi accident. Along these lines, it is essential that a verification and validation procedure to be carried out with RELAP5 code in the simulation of this phenomenon.

Considering this aspect, the purpose of this paper is to present results comparison of computer codes RELAP5-mod3 and RELAP5-3D with experimental data for two-phase flow natural circulation analysis.

2. METHOD AND IMPROVEMENTS

Both RELAP5-3D and RELAP5-mod3 adopt the semi-implicit numerical solution scheme**,** which is based on replacing the system of differential equations with a system of finite difference equations partially implicit in time. The terms evaluated implicitly are identified as the scheme is developed. In all cases, the implicit terms are formulated to be linear in the dependent variables at new time. This results in a linear time-advancement matrix. RELAP5-3D solves this matrix by direct inversion using the default **B**order-**P**rofile **L**ower **U**pper (BPLU) solver. RELAP5-mod3 solves the same matrix using the **L**ower **U**pper (LU) solver. Therefore, comparing the two versions, the differences between codes for this type of simulation are the computational implementation and the solvers.

For both codes, the difference equations are based on the concept of a control volume, or mesh cell, in which mass and energy are conserved by equating accumulation to the rate of mass and energy in through the cell boundaries minus the rate of mass and energy out through the cell boundaries plus the source terms. This model results in defining mass and energy volume average properties and requiring knowledge of velocities at the volume boundaries. The velocities at boundaries are most conveniently defined through use of momentum control volumes centered on the mass and energy cell boundaries. This approach results in a numerical scheme having a staggered spatial mesh. The scalar properties, pressure (P), specific internal energies (U), and void fraction (α_g), of the flow are defined at cell centers, and vector quantities, velocities (V_g,V_f) are defined on the cell boundaries. The resulting one-dimensional spatial noding is illustrated in Fig. 1. The term cell means an increment in the spatial variable, x, corresponding to the mass and energy control volume.

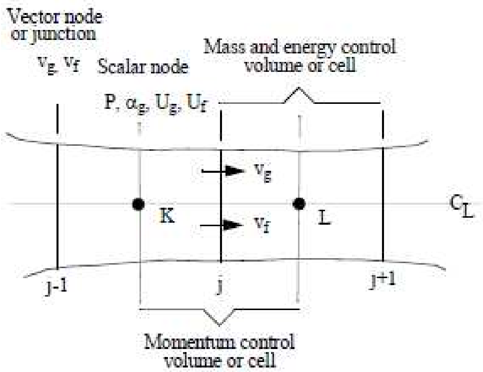

Figure 1: Difference equation nodalization schematic [1].

Time stepping is an important component of the numerical models. It is necessary to choose appropriately the time step to minimize both the execution time of the code and the error of the models. The time step in RELAP5 is constrained by numerous conditions; namely user input, code stability and code error control. The user input includes the maximum and minimum time step sizes, the frequency of plots, printed output, restart record dumps and optional error control specifications. The semi-implicit time step method keeps the time step below the Material Courant Limit (MCL) for code stability. For the best code execution time, the time step ideally should be just below the MCL. However, the time step may never exceed the user-supplied maximum step size, which can be far below the MCL. In this case, the maximum time step size was set with value below the limit. Therefore, the same time step, equal to the maximum value, was used for the simulations in both versions.

3. EXPERIMENTAL CIRCUIT

The experimental circuit [3] consists in a rectangular glass loop with an electrical heat source and a coil cooler, as showed schematically in Fig. 2. Glass is used in the circuit to allow the flow visualization as to identify the flow patterns. The heated section is a 75 mm cylindrical glass tube with two electrical heaters with 76.2 mm diameter, 880 mm high and 8 mm of thickness. The power applied is controlled in the range of 0 to approximately 8600 W. The cooler is all made in glass with 33 mm internal diameter, 610 mm high and 2 parallel coils.

For the simulation of two-phase flow the following operating conditions were assumed:

- ✓ Power dissipated in the heater: 6536 W;
- ✓ Pressure: 1 bar;
- ✓ Coolant: water;
- ✓ Cooling water flow rate: 0.0233 kg/s;
- ✓ Initial temperature: 20 ºC; and
- ✓ Ambient temperature**:** 20 ºC.

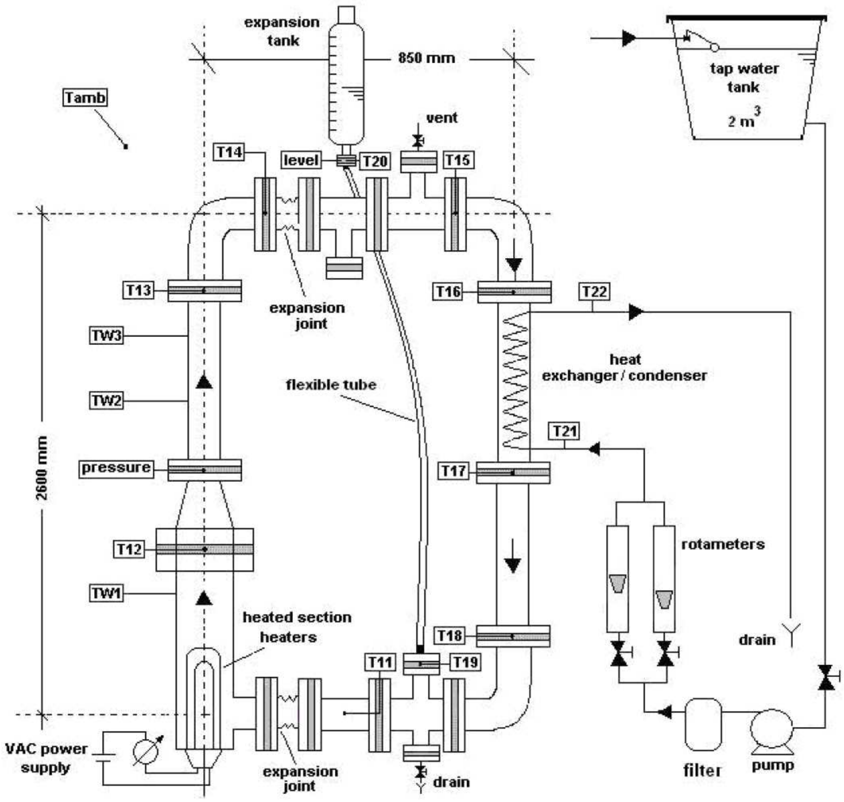

Figure 2: Loop diagram [3].

4. RESULTS

To represent the thermal-hydraulic circuit the PIPE, BRANCH and others hydrodynamic components and the HEAT STRUCTURE of RELAP5 code were used. Figure 3 shows the nodalization employed to analyze the loop. The test started with mass flow rate equal to zero and the power equal to the total value. As RELAP-3D accepts the same input of the RELAP5-mod3**,** the inputs were identical and including the same time step.

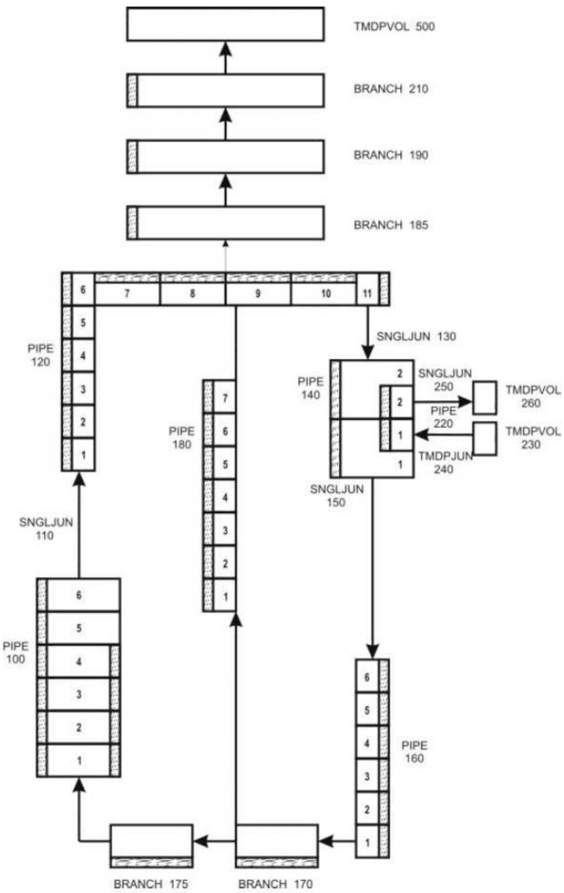

Figure 3: RELAP5 nodalization of the loop.

Figure 4 shows a comparison between the heater outlet temperatures obtained with RELAP5-mod3, RELAP5-3D and experimental data. There are several reasons why the results do not have a very good agreement with the experimental data as follows: the heat transfer coefficient is not specific for natural convection; the calculation of the localized pressure drop is not completely accurate; etc. However, the quality of the results represents well the phenomenon. Until around 1400 s both versions have very similar results and a difference with respect to the experimental data can be explained by the reasons mentioned above. From this moment, when two-phase flow occurs, the transient enters in an oscillatory behavior with a virtually constant frequency and amplitude. RELAP5-mod3 follows this oscillatory behavior with damped manner, with smaller amplitudes and higher frequencies than the experimental data. RELAP5-3D follows this oscillatory behavior too, but results have a better agreement with the experimental data than the previous version, both in amplitude and frequency. The reason for the differences lies in the use of different solvers [4]. Figure 5 shows a comparison between the cooler outlet temperatures obtained with RELAP5-mod3, RELAP5-3D and experimental data and Figure 6 shows a comparison between the secondary outlet temperatures obtained with RELAP5-mod3, RELAP5-3D and experimental data. The same analysis performed for Fig. 4 can be repeated for Figs. 5 and 6, in this case the oscillation amplitude of the experimental data was higher than the two versions of RELAP5. The relevant fact is that the start time of the wave-type oscillations, when the two-phase flow takes place, provided from RELAP5 versions have a good agreement with the experimental data.

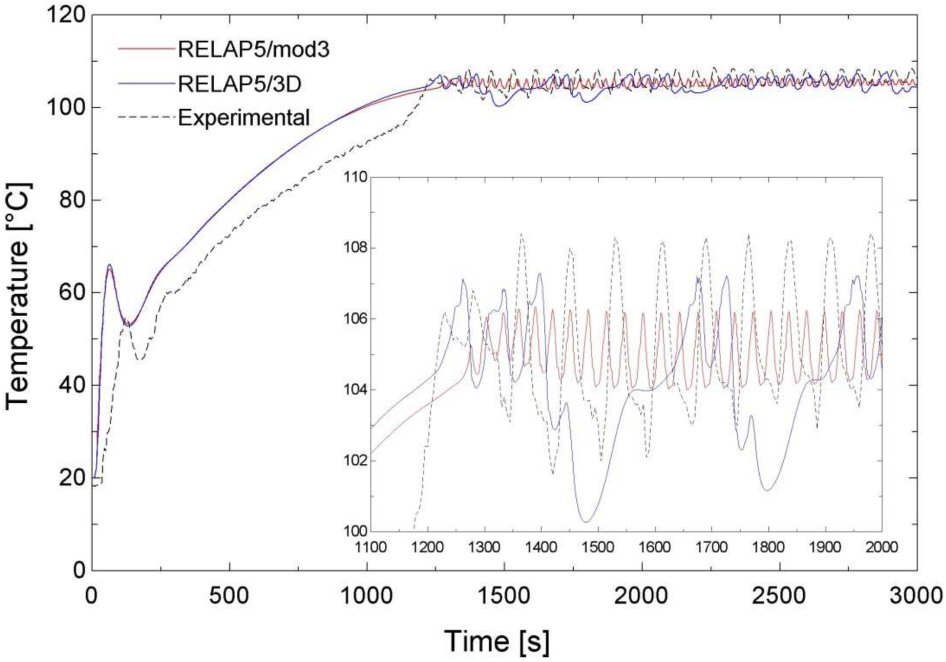

Figure 4: Heater outlet temperature versus time.

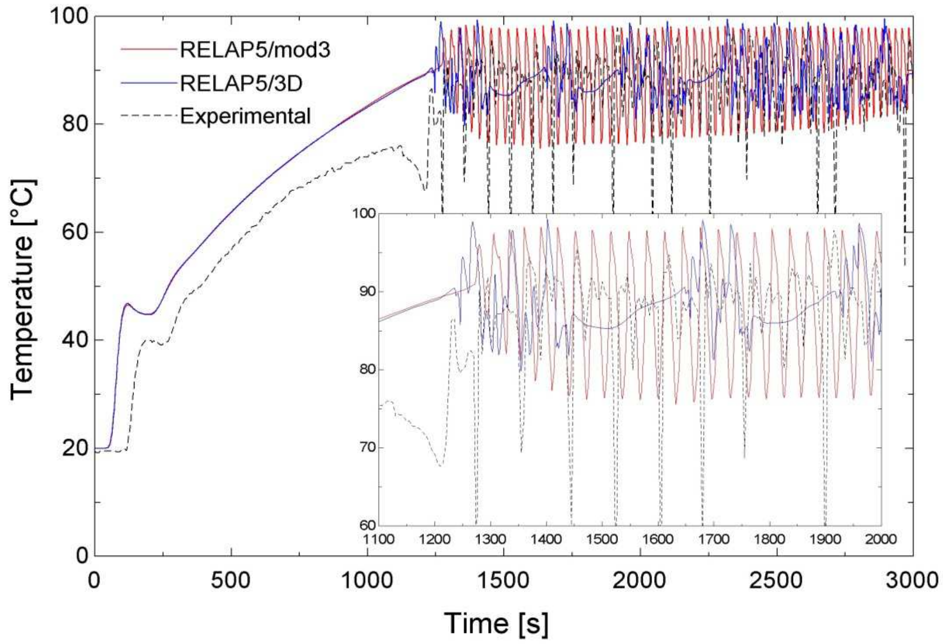

Figure 5: Cooler outlet temperature versus time.

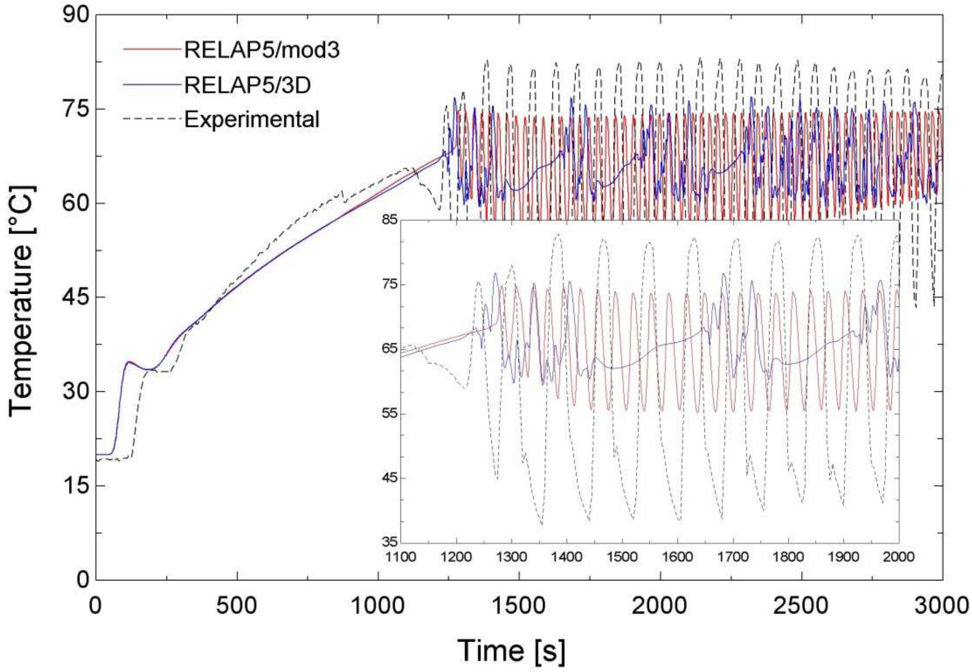

Figure 6: Secondary outlet temperature versus time.

Figure 7 compares the heater output flow for both versions of RELAP5. For this variable there is not experimental data for comparison. While the fluid remains single-phase the results of both versions are practically coincident, but when two-phase flow occurs discrepancies start to appear. The amplitude and frequency of RELAP5-mod3 are larger than the other version, mainly for the negative peak of mass flow.

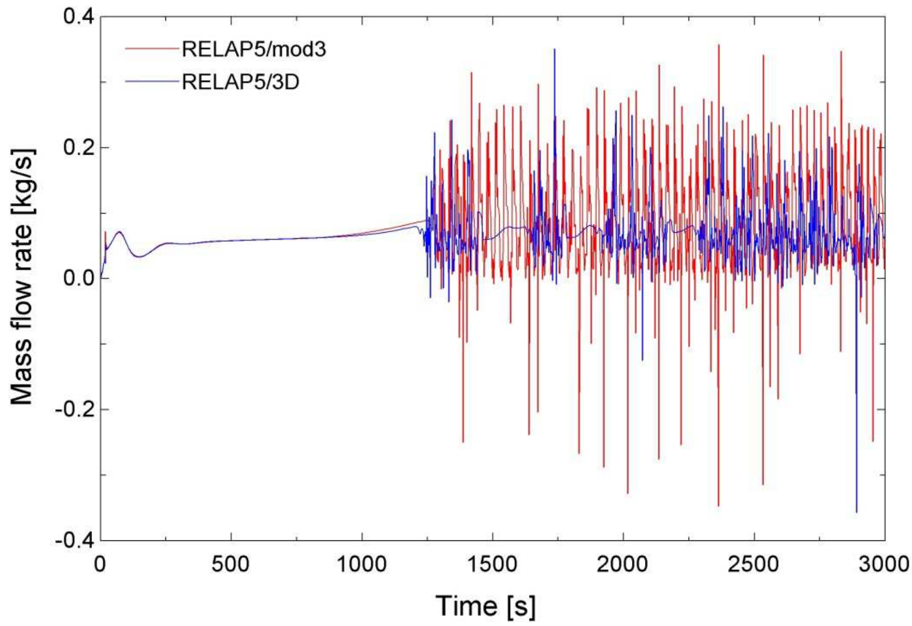

Figure 7. Heater mass flow rate versus time.

5. CONCLUSIONS

The purpose of this study was to compare RELAP5-mod3 and RELAP5-3D code versions for the analysis of two-phase natural circulation loop. Both versions use the same numerical methods of solution of the equations, the semi-implicit scheme, and the inputs are identical, including the time step.

The results of both versions represent well the phenomenon and are close to each other in the single-phase flow region. When the two-phase flow occurs, the oscillatory behaviors of the results were different. RELAP5-mod3 follows this oscillatory behavior with damped manner, i. e. with smaller amplitudes and higher frequencies than the experimental data. RELAP5-3D follows this oscillatory behavior too, but its results are closer to the experimental data than the previous version, when the amplitude and frequency are compared. The solvers are the unique difference between the versions and they are considered as the reason for these different agreements. This work is a further step towards validating the RELAP5 calculation for this type of two-phase application. The version RELAP5-3D was considered better than RELAP5-mod3.

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