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DEVELOPMENT OF A LABVIEW WEB-BASED SIMULATOR FOR RELAP5

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ABSTRACT

This work presents the development of a LabVIEW web-based simulator using the output results of the best-estimate nuclear system analysis code, RELAP5, for graphical user interfaces and web-casting. A numerical based model designed for natural circulation studies on the thermal hydraulic experimental facility called Natural Circulation Circuit, was developed with RELAP5 code. Specific output results from RELAP5 simulation are displayed in a user friendly graphical format. The temperatures are shown as a function of time in a XY graphic. Temperatures, levels and void fractions are displayed in color-coded scale which change in time on the graphical interface representing the circuit. An alarm is set for the case of onset boiling temperature occurrence at the heater outlet. This simulator allows an easy visual understanding of the thermal hydraulic circuit behavior. It can be shared, via Web, with researchers in any geographical location and, at the same time, it can be used in learning for distance educational purposes. In future work, this LabVIEW simulator will be coupled with RELAP5 code through dll's. Simultaneous graphical displaying and code calculations will be possible. Results are presented and discussed.

1. INTRODUCTION

Advanced computing plays a critical role in the design, licensing and operation of nuclear power plants. The modern nuclear reactor system operates at such a complexity level that human reasoning, and simple theoretical models, are simply not able to bring light to a full understanding of a system's response to some proposed perturbation, although acquiring such understanding is an inherent need. Over the last 30 years or so, there has been a concerted effort on the part of the power utilities, as the NRC and other foreign organizations to develop advanced computational tools for simulating reactor system thermal-hydraulic behavior during real and hypothetical transient scenarios. In particular, thermal hydraulics codes are used to analyze loss of coolant accidents (LOCAs) and system transients in light-water nuclear reactors. The lessons learned from simulations carried out with these tools help to form the basis for decisions to be made concerning plant design, operation, and safety [21]. The main thermo hydraulic and accident analysis computer codes used are: RELAP5 [22], TRACE [20], RETRAN [3]; CATHARE [2] and MARS [8].

Currently, after the development of advanced computer technologies, these codes can run on any personal computer. One of the factors limiting the use of these codes on a large scale is the difficult and complicated structure of input/output from these programs (I/O structure). The development of friendly graphical user interfaces (GUI) improves efficiency in interpreting the results of advanced computer codes [11].

The first GUI for the RELAP5 computer code was called the Nuclear Plant Analyzer (NPA) [18]. Later, several other such interfaces have been built. The development of Symbolic Nuclear Analysis Package (SNAP) started in 1996 [5] and is still being developed. SNAP supports the RELAP5 and TRACE analysis codes. A GUI called GUITHARE was developed over the last few years. When it is used for pre-processing, GUITHARE is a helpful interface to create an input deck. Existing input decks can also be imported and modified. All these facilities are interactive. For post-processing, GUITHARE is also an interactive tool, very helpful to analyze calculations results [6]. A SNAP animation model of Krsko nuclear power plant was developed for RELAP5 calculations with the aim to help results analysis [15]. In addition, reference calculations for validation of Krsko full scope simulator were performed with the latest RELAP5/MOD3.3 code and compared to previous RELAP5 versions to provide verified source data, needed to be demonstrated on an animation model. An advanced simulator was successfully developed for the advanced boiling water reactor (ABWR) plant to support various applications before and after commercial operation. This specific plant simulator was developed based on two separate RELAP5-3D modules synchronized on a commercial simulation platform, namely 3-Key Master. On this advanced plant simulation platform, major plant dynamics were simulated by two separate RELAP5-3D modules, one for reactor system modeling and the other for balance of plant system modeling [24]. A severe accident management advisory system with training simulator, nominated SAMAT, was developed as an all available information source for severe accidents, and were re-organized and provided to management staff in order to reduce uncertainties. This developed system includes a graphical display for plant and equipment status, a previous research results summary by knowledge-base technique, and the expected plant behavior using the severe accident training simulator. The plant model used in this paper is oriented to severe accident phenomena and thus can be used to simulate the plant behavior for a severe accident [9]. An environment formed by a simulation kernel with a set of tools aiming at the reusable components building. These simulators are being used for future operators training in a safe way and are based on a complex architecture of simulation models with real-time constraints involving many different applications where modern object-oriented methodologies and technologies have been applied [4].

To develop a friendly web-based GUI for the RELAP5, LabVIEW (Laboratory Virtual Instrument Engineering Workbench) was used. LabVIEW is a graphical programming environment to develop sophisticated measurement, test, and control systems using intuitive graphical icons and wires that resembles a flowchart [13].

This work presents the development of a web-based simulator (WBS) in LabVIEW environment using the output results of RELAP5, the best-estimate nuclear system analysis code. A numerical based model designed for natural circulation studies on the thermal hydraulic experimental facility called Natural Circulation Circuit (NCC), was developed with RELAP5 code. However, the methodology used here for the WBS is very general, and it can be easily extended to other system analysis codes.

The work also presents a description of the NCC experimental facility, the RELAP5 theoretical model based on NCC, methodology and tools, including the Visual Basic for

Application (VBA) program used for RELAP5 output data post processing, the friendly LabVIEW developed GUI's (simulators) for RELAP5, and finally conclusions are discussed.

2. EXPERIMENTAL FACILITY

NCC facility in Nuclear Engineering Center at IPEN is an experimental circuit constructed to provide thermal hydraulic data and information about phenomenology involved under single and two phase natural circulation conditions [19].

It is a rectangular assembly (2600 mm height and 850 mm wide) made of temperature resistant borosilicate glass tubes of 38.1 mm internal diameter and 4.42 mm thickness.

It has a heated section, also in glass tube of 76.2 mm internal diameter and 880 mm length, with two stainless steel cladding Ni-Cr alloy electric heaters in U form, connected in parallel with an electric power supply. Heaters H1 and H2 are fed with 220 VAC nominal voltage. H1 heater operates always at maximum power after turned on and has no adjustment (4,4 kW). Electric power in the H2 heater is adjusted by a variac in the range of 0 to 100% supply level (0 to 4,2 kW). Heaters external diameter is 8.5 mm and the U total length is 1200 mm.

The cooled section consists of a heat exchanger/condenser, also in glass, with two internal spiral coils where cooling water flows. Tap water is pumped from a 2 m^3 reservoir to the heat exchanger/condenser with the desired cooling flow rate and is measured by two rotameters.

Circuit has an expansion tank opened to atmosphere in order to accommodate fluid density changes due to the temperature and void fraction changes. This tank is connected to the circuit through a flexible tube at its lower region in order to prevent steam entrance. Approximately twelve liters of demineralised water are used to fill the circuit.

Fifteen 1.5 mm K type (Chromel-Alumel) ungrounded thermocouples are distributed along the circuit to measure fluid and ambient temperatures. TEFLON™ sleeves were made to install these thermocouples between the glass tubes. Metallic connections with "O-rings" are also used to install the thermocouples along the circuit. Three K type thermocouples with exposed junction are attached to the glass tube wall of for measurements at the circuit hot leg.

Two differential pressure sensors [23], called P1 and P2 are used to measure relative pressure at the heaters outlet and the expansion tank water level, respectively. All instruments were calibrated in the laboratory. Electric signals from instruments are sent to a Data Acquisition System [14]. Fig. 1 and Fig. 2 show a schematic draw and a photo of this facility.

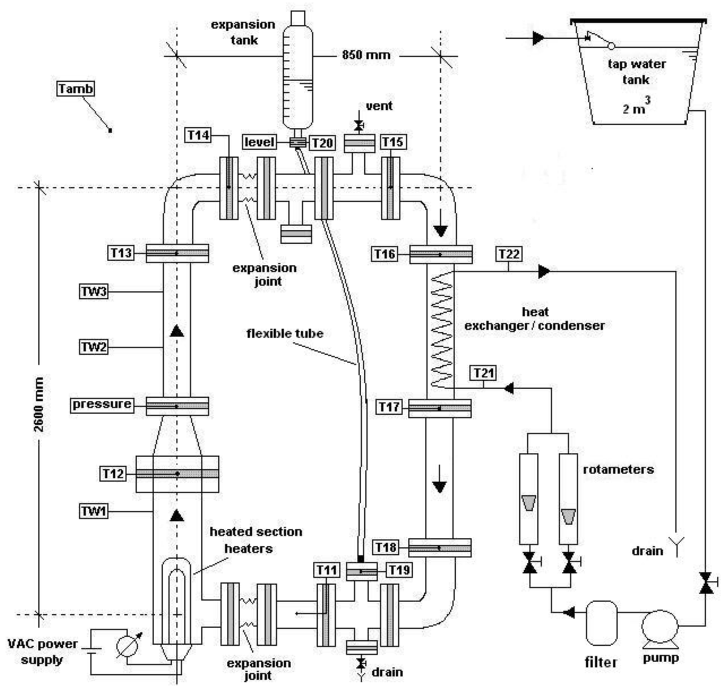

Figure 1. Schematic draw of the natural circulation facility.

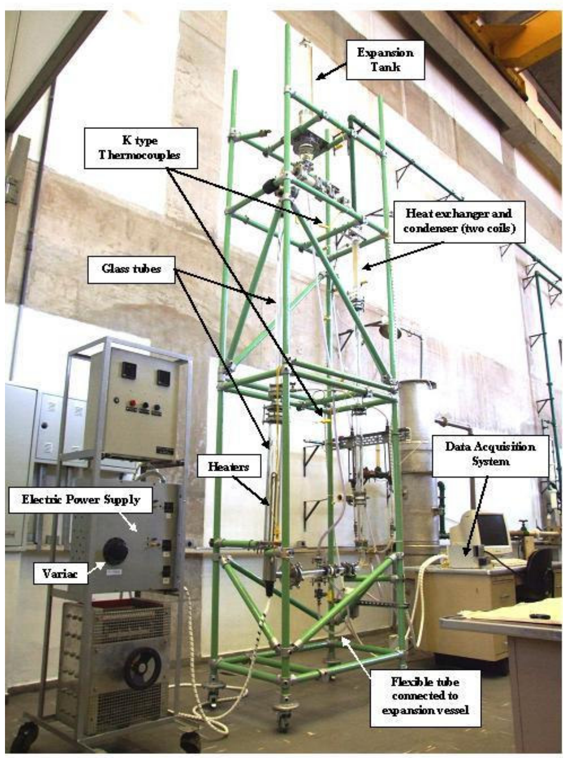

Figure 2. Natural circulation facility.

3. RELAP5 THEORETICAL MODEL

To simulate the thermal hydraulic behavior of the NCC, a new nodalization was developed using PIPE and BRANCH components to represent all the circuit [1]. At the beginning, all the volumes were filled with water except the one at the upper part of expansion tank, which had also some air. Heat losses to the environment were also considered. This model was able to predict the the one and two-phase flow experiments behavior. Experiments showed that two-phase oscillations only begins when the upper part of the hot leg becomes completely filled with vapor. The saturation temperature is considered as the temperature to liquid to vapor phase change, under the circuit pressure, disregarding the non-condensable gases presence [16]. The initial conditions for two-phase flow simulation are equal to 8,030 W, 0.03 kg/s, 25 °C and 19 °C for the power, cooling water flow, initial and environment temperatures respectively. RELAP5 nodalisation is presented in Fig. 3.

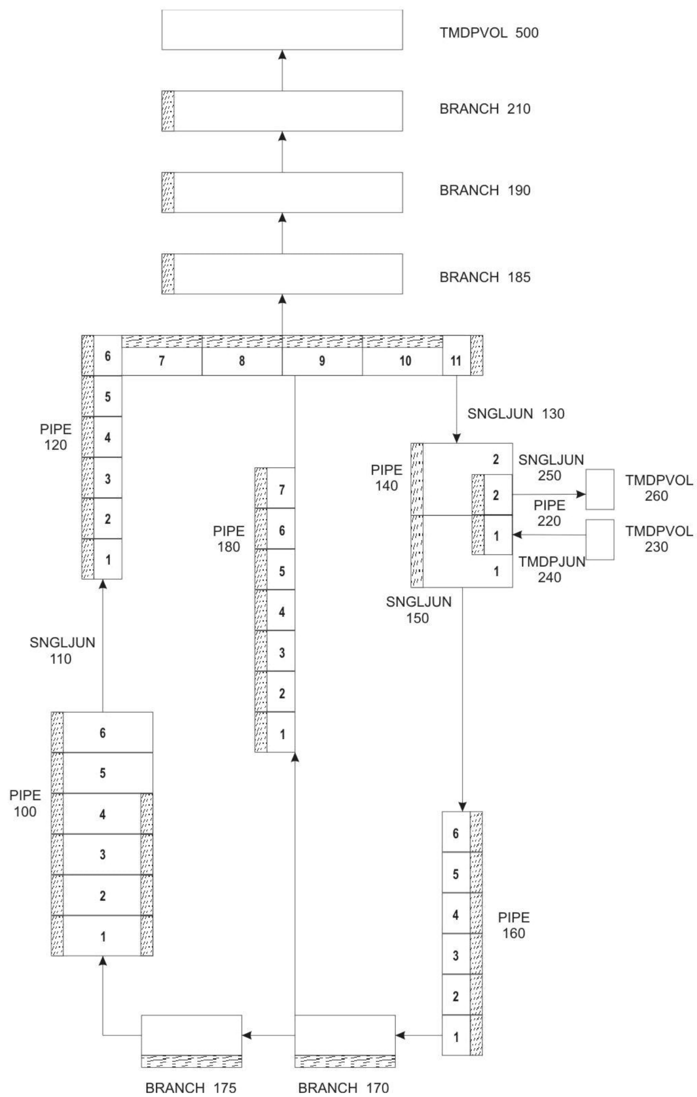

Figure 3. RELAP5 - NCC nodalisation.

Table 2 shows the association of components between RELAP5 nodalisation and the circuit.

Table 2. Nodalisation of the natural circulation experimental facility

COMPONENT	COMPONENT NUMBER	COMPONENT TYPE
Heater	100	PIPE
Hot Leg	120	PIPE
Primary Cooler (outlet)	140 150	PIPE SNGLJUN
Cold Leg	160 170 175	PIPE BRANCH BRANCH
Surge Line	180	PIPE
Expansion Tank	185 190 210	BRANCH BRANCH BRANCH
Secondary Cooler Cooling Water (inlet)	220 230 240	PIPE TMDPVOL TMDPJUN
Cooling Water (outlet)	250 260	SNGLJUN TMDPVOL
Containment	500	TMDPVOL

4. METHOLOGY AND TOOLS

The methodology and tools used to develop a WBS for the RELAP5 are presented below.

4.1. Visual Basic for Application (VBA) Program – Strip Program

RELAP5 output data are stored in the restart-plot file (binary file with .rst extension). The restart-plot file contains all calculation parameters (pressures, temperatures, void fractions, flow rates, etc.) needed for the entire RELAP5 transient calculation. The Strip program was used for RELAP5 output data post processing and is an Excel Visual Basic for Application (VBA) macro [17]. It can read the RELAP5 restart-plot binary output file and, through a GUI, transient data can be chosed and imported to an Excel worksheet directly. The Strip program can also do some data unit conversion as well as export these data to other program such as Grapher [7].

For the WBS development the following variables calculated in the NCC simulation with RELAP5 were used: time (t – seconds), environment (T_{amb}), fluid (T11 to T22) and wall (TW1 to TW3) temperatures (°C), mass flow (kg/s), expansion tank level (m), void fractions (0 to 100%) and the volume levels (m) nodalisation . Fig. 4 shows the Strip program front panel for RELAP5 calculated temperatures presentation. The interface was developed in

Portuguese language. RELAP5 calculated temperatures are selected and exported to an Excel spreadsheet as shown in Fig. 5. The first column indicates the transitory time and remaining columns indicate the calculated temperatures. The others RELAP5 calculated variables are exported the same way.

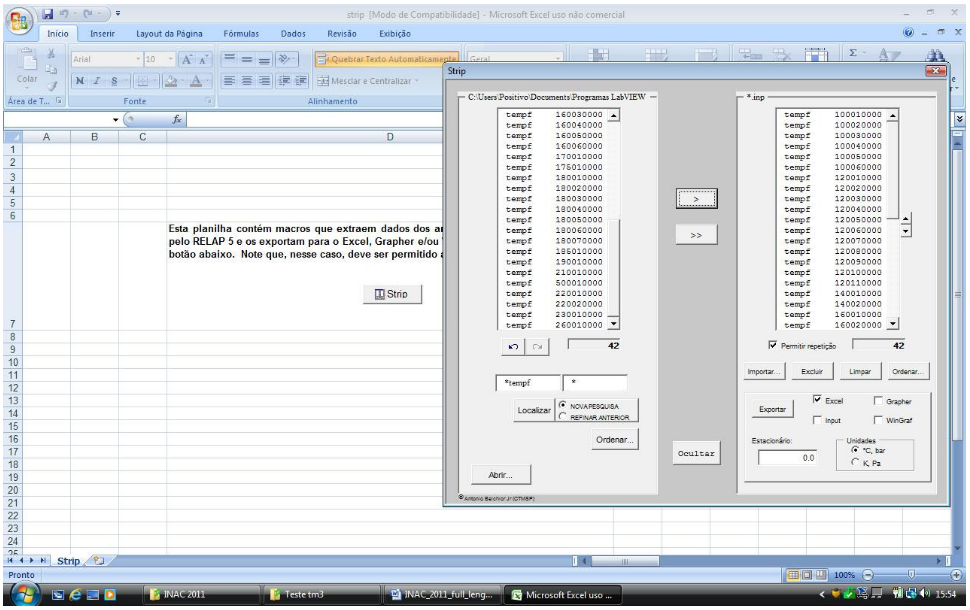

Figure 4. Strip program – front panel.

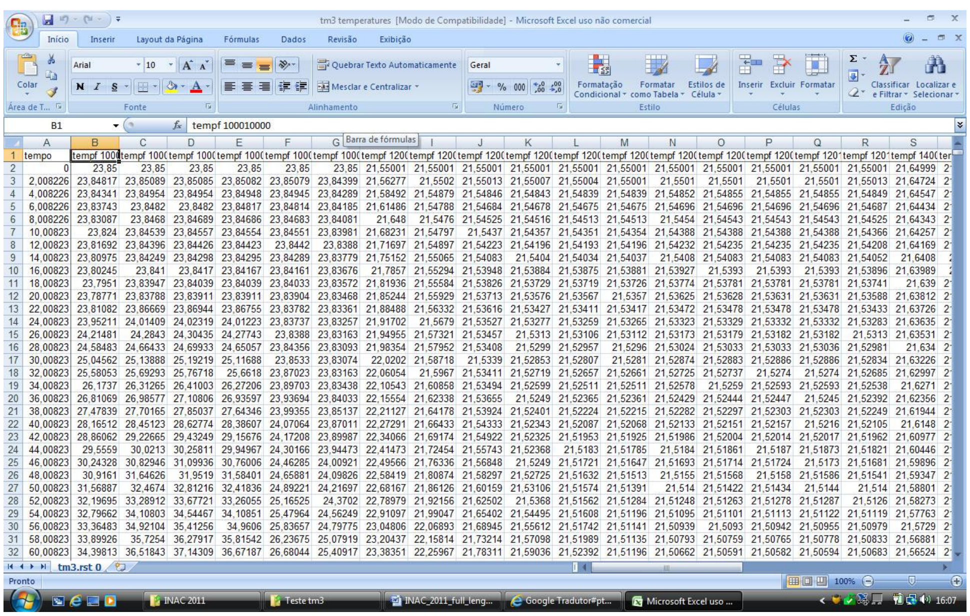

Figure 5. Excel spreadsheet – RELAP5 calculated temperatures.

4.2. LabVIEW WBS for RELAP5 - WBS

LabVIEW 2009 [12] was used to develop a WBS for RELAP5. It is a development platform based on the G language (graphical programming language) that uses icons instead of command lines to create applications. LabVIEW programming is based on the stream of data, where data determine the performance, bringing some advantages for scientific and engineering applications, especially in data acquisition systems (DAQ). The codes are added in a diagram block using functions graphical representations to control the front panel added objects . Once created, the diagram block is compiled into machine language.

The WBS developed with LabVIEW can also be shared with other researchers, on the World Wide Web, in real time (web-casting). Currently, with personal computers access advances, the Web is being available, from anywhere in the world, with high speed. The WBS is very useful for teamwork when there is a need to share results in real time, allowing research teams interaction through many geographically distant regions [10]. Schematic diagram of LabVIEW remote panels used for results web-casting are shown in Fig. 6.

Figure 6. Schematic diagram of LabVIEW remote panels.

NCC transient simulation performed by RELAP5 code produced a large amount of calculated data stored in output file (restart-plot file). WBS was designed to provide graphical displays of these pos-transient simulation results so that users can easily follow NCC thermal hydraulic behavior.

Figure 7 shows the WBS diagram block developed in LabVIEW environment. The Excel file from Strip program in txt format is open/read (Fig. 7 (A), being concatenated as a string and written step by step by a programming structure called for loop (Fig. 7 (B)). After that, it is converted to a defined dimension array (Fig. 7 (C)) and separated on selected variables (Fig. 7 (D)) that will be displayed in a XY graphical format and in color-coded scale that changes in time on the graphical interface representing the NCC.

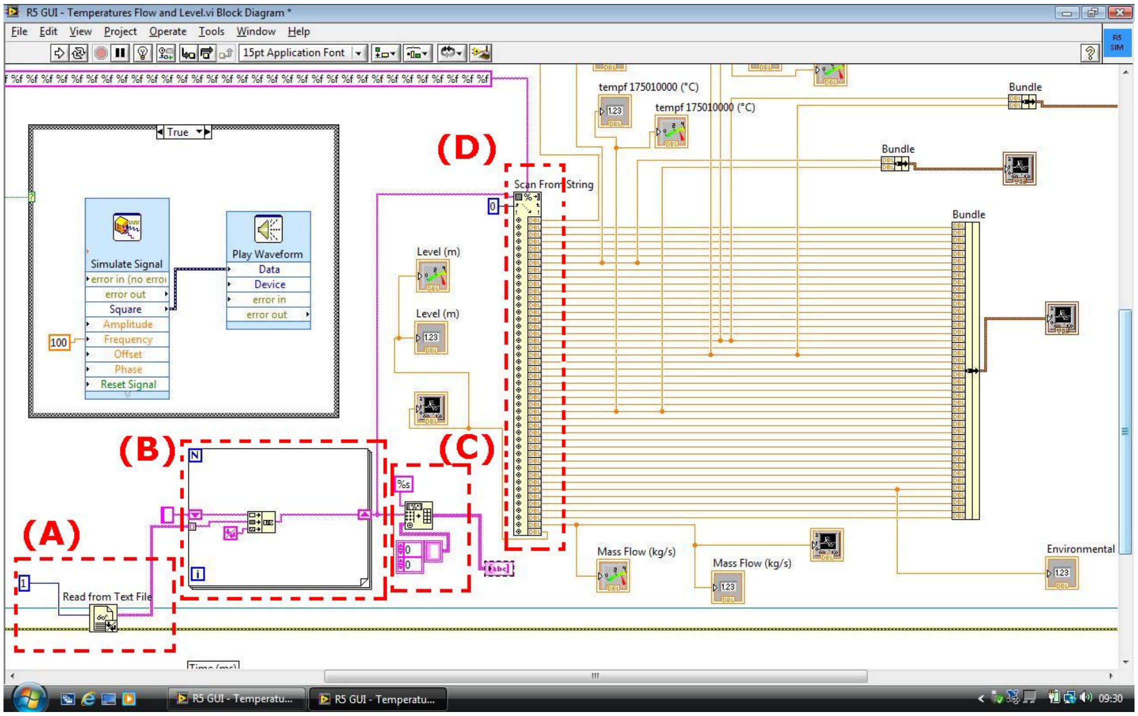

Figure 7. WBS – LabVIEW block diagram.

The WBS consists of three friendly web-based GUI's that can be accessed to display a wide range of data. Each GUI is provided with two alarms, one for the case of onset boiling temperature occurrence at the heater outlet (100 to 102 °C) and the other to indicate the simulation final instants (5,500 to 5,600 s). The GUI's are described below.

4.2.1. GUI – NCC (XY graphical format): temperatures, flow and expansion tank level

Fig. 8 presents the GUI - NCC (XY graphical format) front panel where the temperatures, flow and expansion tank level are shown as a function of time in a XY graphic (steps of 2 s). The simulation velocity can be increased or decreased through the (A) switch. The 2D table (B) shows the NCC simulated variables (temperatures, mass flow and expansion tank level) as a function of time. The 2D table data are displayed row by row. The environment temperature is presented in (C) and other XY graphics can be displayed by selecting the corresponding tab on the GUI - NCC (XY graphical format) front panel, such as inlet and outlet heater temperatures (D), inlet and outlet heat exchanger temperatures (E), mass flow (F) and expansion tank level (G). Simulation time indicator (s) is showed in (H).

4.2.2. GUI – NCC (color-coded scale): temperatures, void fractions and levels

Temperatures, void fractions and levels are displayed in color-coded scale changing in time on the graphical interface representing the RELAP5 NCC nodalisation. Figure 9 shows the

GUI – NCC (color-coded scale) – temperatures and void fractions in front panel. The heater outlet temperature is displayed in (A).

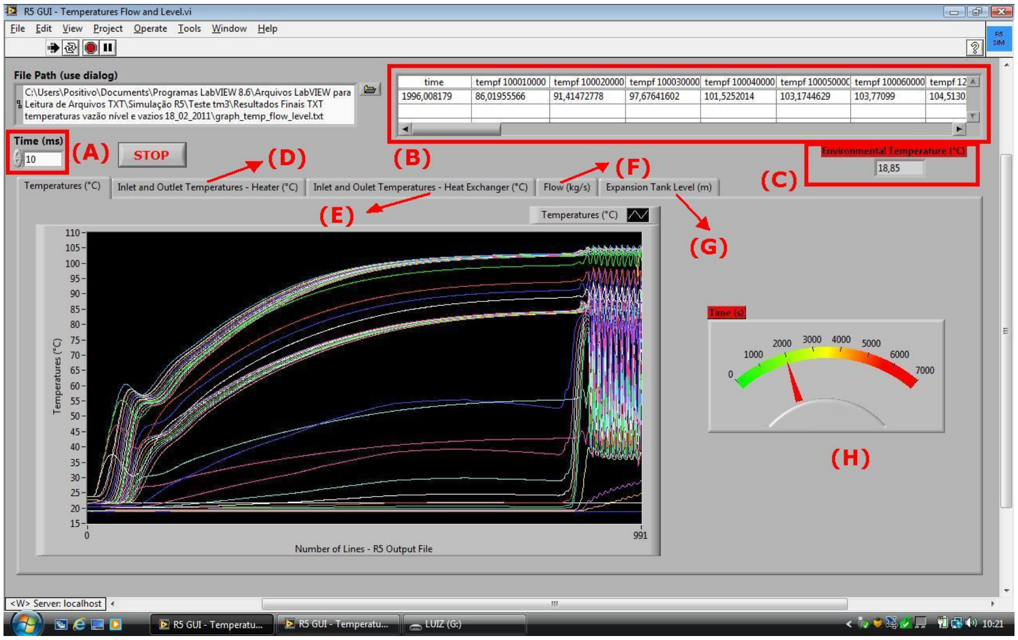

Figure 8. GUI - NCC (XY graphical format) front panel.

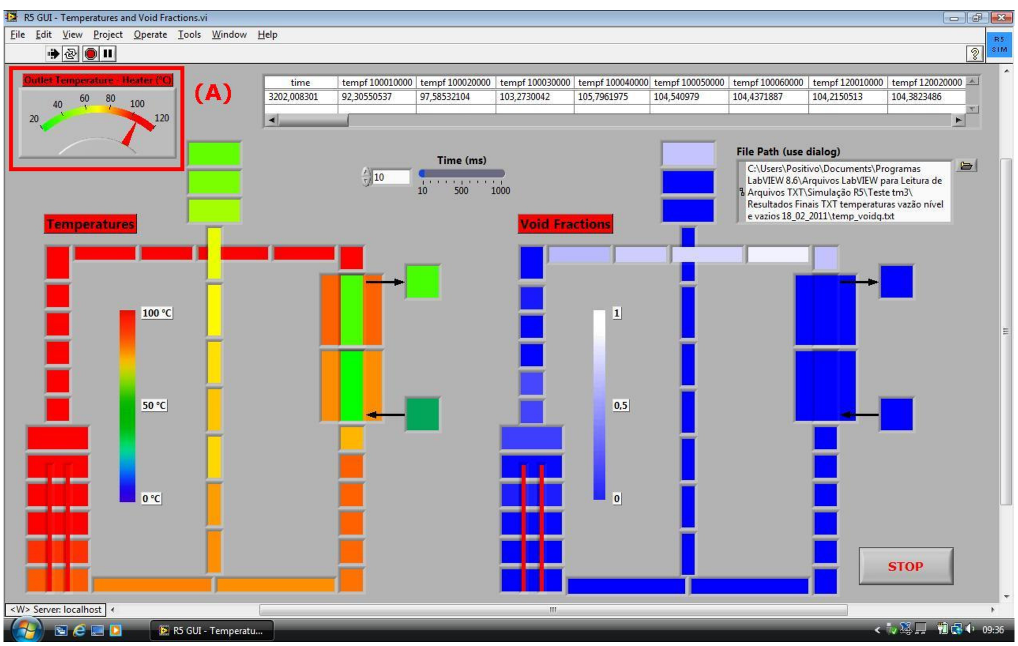

Figure 9. GUI – NCC (color-coded scale) – temperatures and void fractions front panel.

GUI – NCC (color coded scale) – temperatures and levels front panel is presented in Fig. 10. The variables called voidf multiplied by the height of the RELAP5 nodalisation volumes results in liquid levels.

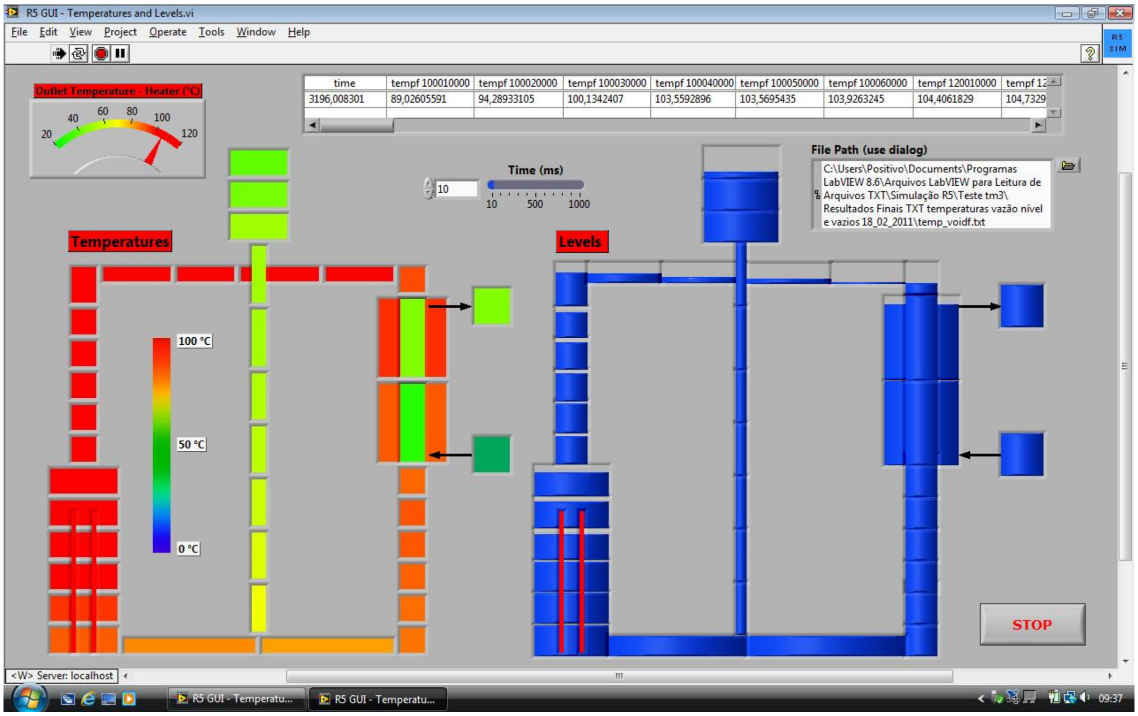

Figure 10. GUI – NCC (color-coded scale) – temperatures and levels front panel.

5. CONCLUSIONS

This work presented the development of a LabVIEW web-based simulator using the output results of the best-estimate nuclear system analysis code, RELAP5, for graphical user interfaces and web-casting. The output results were based on RELAP5 numerical simulations of the Natural Circulation Circuit facility in Nuclear Engineering Center at IPEN.

The methodology used for developing of the LabVIEW web-based simulator is very general, and can be easily extended to other system-analysis codes and experimental facilities. This is possible by changing of the programs used for codes output data post-processing and data display windows minor modifications.

The web-based simulator was developed in LabVIEW, which is a graphical language based program with excellent graphics and visual resources. The developed simulator can also be shared with other researchers, on the World Wide Web, in real time (web-casting), allowing the research teams interaction of over geographically distant located regions.

The three friendly web-based graphical user interfaces allows an easier visual understanding of Natural Circulation Circuit thermal hydraulic behavior.

In future work, the LabVIEW simulator will be coupled with RELAP5 code, through dynamic link libraries that can be developed for most nuclear power plants. Simultaneous graphical displaying and code calculations will be possible.

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