2011 International Nuclear Atlantic Conference - INAC 2011
Belo Horizonte,MG, Brazil, October 24-28, 2011
ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR - ABEN
ISBN: **978-85-99141-04-5**

DEVELOPMENT OF A COMPUTER CODE FOR DYNAMIC ANALYSIS OF THE PRIMARY CIRCUIT OF ADVANCED REACTORS

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ABSTRACT

Currently, advanced reactors are being developed, seeking for enhanced safety, better performance and low environmental impacts. Reactor designs must follow several steps and numerous tests before a conceptual project could be certified. In this sense, computational tools become indispensable in the preparation of such projects. Thus, this study aimed at the development of a computational tool for thermal-hydraulic analysis by coupling two computer codes to evaluate the influence of transients caused by pressure variations and flow surges in the region of the primary circuit of IRIS reactor between the core and the pressurizer. For the simulation, it was used a situation of "insurge", characterized by the entry of water in the pressurizer, due to the expansion of the refrigerant in the primary circuit. This expansion was represented by a pressure disturbance in step form, through the block "step" of SIMULINK, thus enabling the transient startup. The results showed that the dynamic tool, obtained through the coupling of the codes, generated very satisfactory responses within model limitations, preserving the most important phenomena in the process.

1. INTRODUCTION

The advance of population growth, together with other socioeconomic factors, leads to an increasing exploitation of the energy resources. Nuclear power is a good alternative because it is a direct way of obtaining electricity on a large scale, generating a low environmental impact. The construction of new power plants for electricity generation faces serious challenges in this century, due to levels of concerns and demands of society, being more evident in the case of nuclear technology and now reinforced by Fukushima episode. Requirements related to environment and security extend also to issues regarding to the waste production and proliferation resistance. It is therefore necessary to develop new projects that are in syntony with the demands of society and that are competitive into an economic and financial context of liberalization and deregulation of electricity markets, in which investments are made by the private sector. Usually, this requires a shorter time in returning investments than in the past.

In this context, there are several initiatives aimed at defining the basic criteria necessary for new projects, and also actions to identify those projects that have potential for viability in the medium- and in the long term. The IRIS project seeks to overcome the challenges of introducing improvements in the issues regarding safety, proliferation, radioactive waste and economy [1].

2. THE IRIS REACTOR

The basic concept proposed to achieve these improvements is to develop a pressurized water reactor with an electrical power of 335 MW. This project is being conducted by a consortium of several organizations led by Westingouse Electric Company since 1999.

This project attempts to insert in the market, plants of medium and large powers with multi-modular configuration. It takes advantage of the most extensive experience in the technology of light water reactors (LWR), innovating in its configuration in order to increase safety by eliminating or minimizing the possibility of a series of accidents.

The IRIS reactor design has, then, all components of the primary circuit (steam generators, pumps, pressurizer and core shielding) inside the pressure vessel as shown in Figure 1. This imposes an increase in the mass of water in the primary circuit with a consequent increase in the thermal-hydraulic inertia.

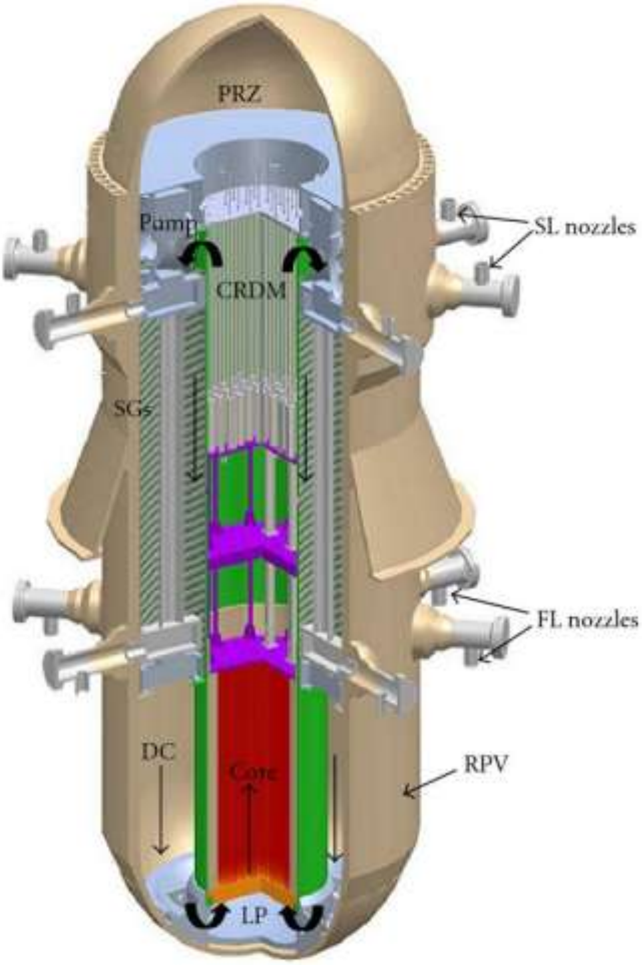


Figure 1. Pressure vessel IRIS and internal details

3. HUMAN-MACHINE INTERFACE SYSTEMS - HMIS

A way to increase security, to reduce risks and to improve economics is through the development of human-machine interface systems - HMIS. Such systems facilitate and assist the operation of the reactor helping to keep the plant in more stable operating regions, decreasing the possibility of unplanned outages, and so increasing the plant availability and its potential financial return.

In the context of the IRIS reactor design, here is sought the development of a computational tool for analyzing its thermal-hydraulics, through the coupling of two computer codes: the MODIRIS [2] (developed in SIMULINK) and MODPRESS [3], in order to assess the influence of transients caused by pressure changes and surge flows in the region of the primary circuit between the core and the pressurizer, using MATLAB software as a platform.

Several works in the nuclear sector reinforce the idea of utilizing HMIS's. Using MODELICA, Cammi [4] presented the development of a suitable simulation tool for the dynamics and the control of the IRIS reactor. Blair [5] developed a work by analyzing the core thermal-hydraulics of IRIS, by introducing a set of computational tools that are designed to streamline the process in execution as well as to take advantage of the large capacity of modern computers to carry out more detailed and comprehensive studies. He provided an interface based on "scripts" (set of instructions for a particular action that the application program will execute) for the analysis through the thermal-hydraulics code VIPRE, using an interface created in MATLAB.

4. MODELING DYNAMIC SYSTEMS - SIMULINK

The SIMULINK is a MATLAB computer package focused on modeling, simulation and analysis of dynamic systems, both linear and nonlinear, continuous and/or discrete in the time. It uses a HMIS for the construction of models from block diagrams. It is a product of a long evolution of simulation packages that require the formulation of differential equations or difference equations in programming languages. It includes block libraries containing fonts, displays, linear and nonlinear components and connectors, with the option of creating or customizing blocks.

Thus, the SIMULINK provides a suitable interface for simulation of such systems. It has also a number of parameters that provide flexibility to the user, allowing, for example, the choice of the numerical method employed in the simulations. Thus, it is possible to adapt a simulation according to the needs of a given system.

4.1. Implementation of the Components of IRIS in MATLAB / SIMULINK.

The MODIRIS is a code that simulates the primary and secondary circuits of the IRIS. Its modeling [2] involves ordinary differential equations, which originate in the study of thermal-hydraulic and neutronic balance of primary and secondary circuits of the IRIS, transformed to models in SIMULINK: each one (or set of them) corresponds to the components of the reactor and is now represented by block diagrams.

For coupling with a model for pressurizers, the code MODPRESS was already available. Its input and output data were restated so that the dynamic interaction between the two codes could advance properly with the time. The code MODPRESS, that represents the model of a conventional pressurizer, was formulated using the Euler numerical method and structured on the platform of MATLAB to solve, approximately, the model equations proposed by Barroso [3].

In addition, other details must be taken into account: the MODPRESS was designed for conventional PWR pressurizers, and later reformulated for IRIS. For the coupling, a MATLAB command to provide the "link" between the two codes was sought. The simplest way was to convert the code MODPRESS in a "function" form of MATLAB. So, MATLAB Function block (Figure 2) was used, creating a virtual block of MODPRESS in SIMULINK. Then, the exchange of information between the two codes could be implemented in order to obtain the desired feedbacks.

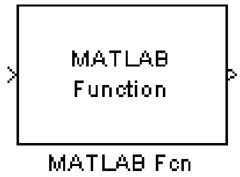


Figure 2. MATLAB Function

The geometric dimensions of the IRIS pressurizer (Fig. 3) for this analysis were preserved. In particular, the volume of vapor (about 44m^3) is in agreement with that proposed by Carelli [6], corresponding to 58% of the total volume of the pressurizer.

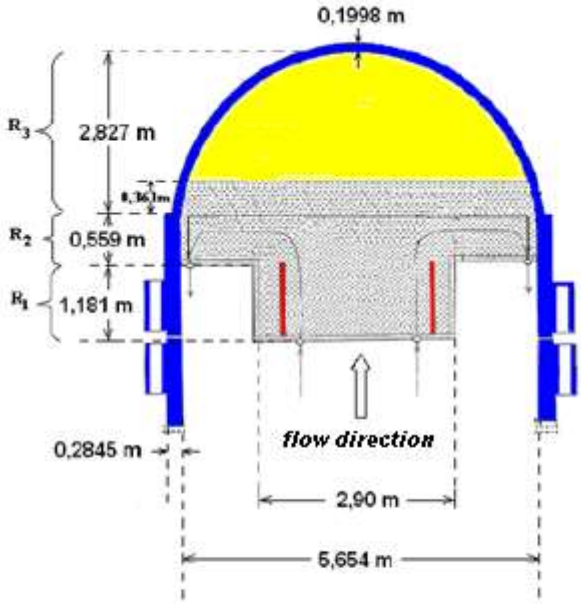


Figura 3. Geometric dimensions of the IRIS pressurizer

After the implementation of new I/O forms for MODPRESS data, a subsystem in SIMULINK was created that represents a simplified mass flow module in the region of interest between the core and the pressurizer, on the basis of a pressure feedback. A major difficulty in preparing the module resides in the lack of a well-defined geometry for the IRIS (remember that there is no prototype). Moreover, the difficulty of analyzing a flow between obstacles such as plates and tubes made it necessary to adopt a simplified geometry.

5. MATHEMATICAL MODELING FOR THE COUPLING

The mathematical modeling strategy adopted for data exchange of pressure and mass flow between the two codes was based on the creation of a simplified module resulting from the implementation of equations that relate mass flow, pressure in the primary circuit and pressure in pressurizer. In addition, the following hypotheses were adopted [7]:

- The pressure in the primary circuit, as in the pressurizer is uniform;
- The fluid density is constant in the path from core exit to pressurizer;
- The surge flow is a function of pressure difference between the primary circuit and pressurizer.
- The numerical time-step is fixed for both codes, having the same value 10^{-2}s.

After the implementation of the equations in the SIMULINK environment, the interface allowed the visualization of data exchange between the two codes. In this interface, there are subsystems that contain specific blocks, each representing a variable, as well as the transactions between them. The module obtained is loaded into the subsystem "pressurizer" (Figure 4). The interface obtained provides a better view of the availability of the reactor components and the visualization of the complete code, which was named MODIACOPLA. It was also convenient to implement an initialization screen and a pop-up window of MODIACOPLA to facilitate the code execution.

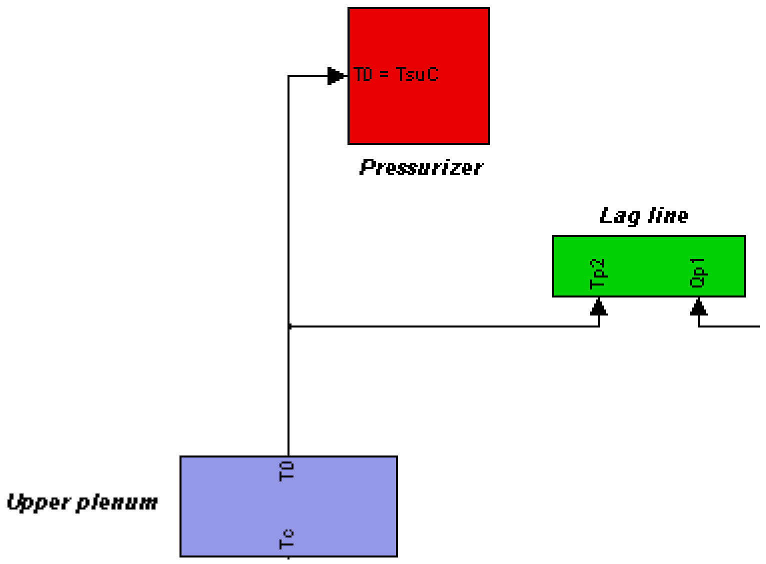


Figure 4. Graphic interface of the subsystem "pressurizer"

6. RESULTS AND DISCUSSIONS

For the simulation, an insurge situation was considered, characterized by the entry of water in the pressurizer, due to the expansion of the moderator in the primary circuit. This expansion was idealized by a step disturbance in primary pressure and performed through the block "step" of SIMULINK. The simulation was initiated with the disturbance at t = 10 s, causing the pressure difference necessary to force a mass flow. At the time t =110 s, the disturbance was removed.

Figure 5 illustrates the time evolution of pressure in the primary circuit. After 10 seconds, there has been a disturbance and a subsequent transient influx, thus representing adequately an expansion of the moderator.

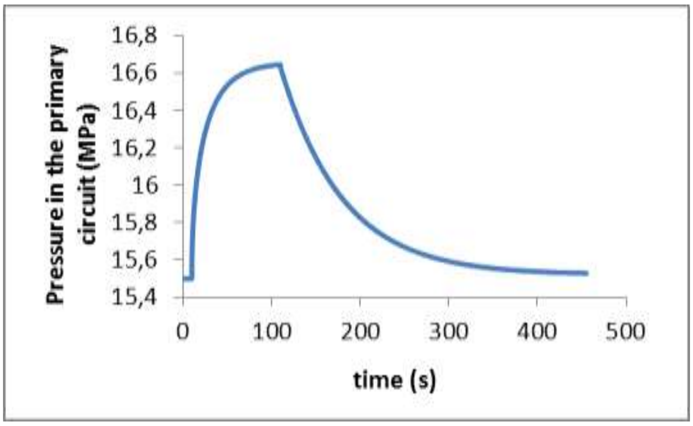
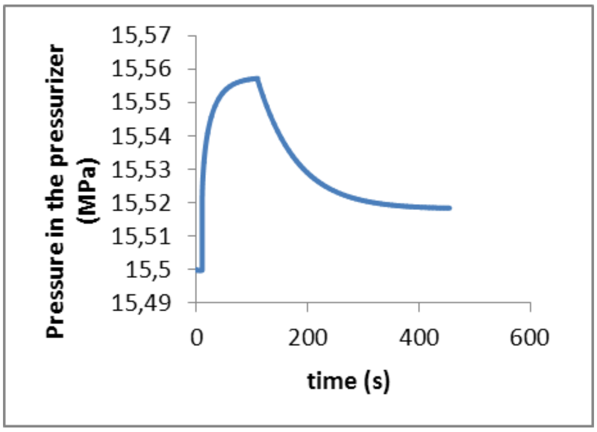


Figure 5: Pressure in the primary circuit

The pressure reached 16.64 MPa in the primary. It was also noted in the above graph a gradual reduction of pressure. This decrease is due to the action of the pressurizer that, with the entry of water, tends to bring the pressure of the primary circuit back to a normal operating situation. The pressure in the primary stabilized at circa 15.53 MPa.

The response of the IRIS pressurizer is shown in Figure 6. At t = 10 s, the pressure begins to increase, reaching a value of 15.56 MPa, stabilizing at circa 15.52 MPa. The variation of pressure in the pressurizer was very limited, what might be explained by the dimensions of the IRIS pressurizer. The large volume of this component tends to dampen in a effective way further increases of the pressure in the primary circuit, avoiding excessive stress in its internal components. The correspondent surge mass flow is shown in Figure 7. After 10s, the influx starts, reaching a value of 15.54 kg/s. At t = 110 s, the flow begins to decrease, reaching a value close to zero, so a new steady state is attained.



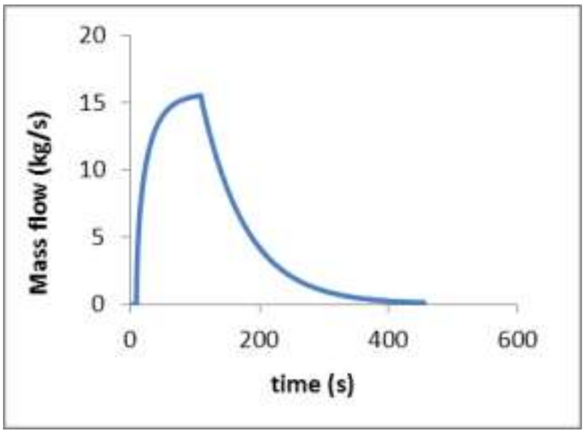
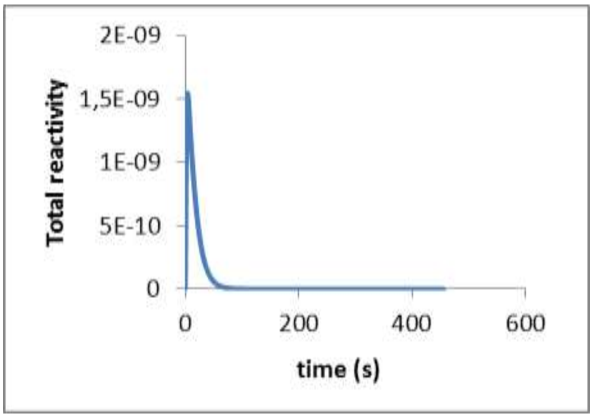


Figure 6. Pressure in the pressurizer

Figure 7. Surge mass flow

Other effects related to this event on some parameters of interest in the primary circuit can be evaluated. For example, despite a loss of 7.8% of primary water inventory to the pressurizer, quantities such as thermal power, fuel temperature and coolant temperature showed no significant variations, indicating a good response from the plant in case of such an event.

Similarly, it was observed that the total, fuel and moderator reactivities (Figs. 8-10) also have not undergone important changes, what can be explained by the insignificant variation in their temperatures.



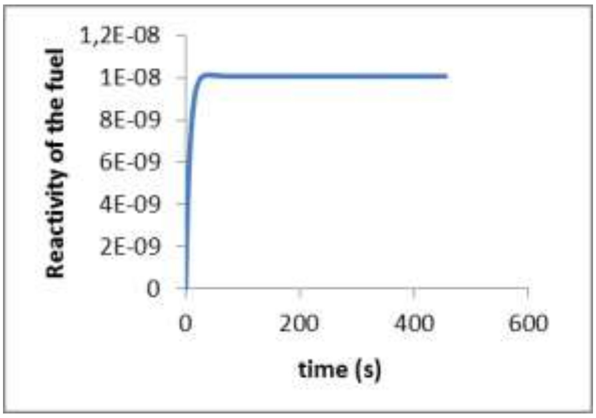


Figure 8. Total reactivity

Figure 9. Reactivity of the fuel

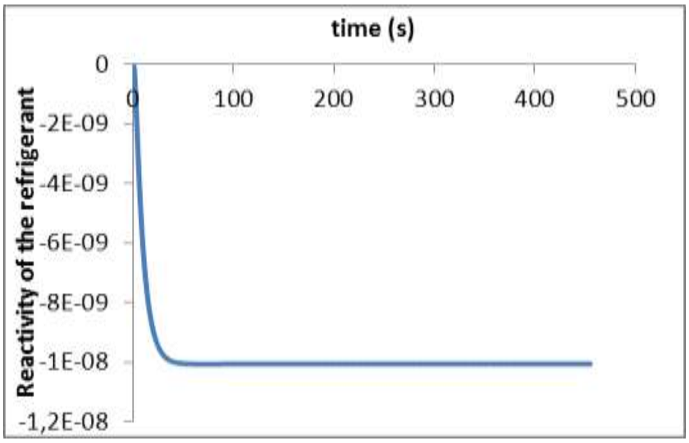


Figure 10. Reactivity of the moderator

7. CONCLUSIONS

Given the main objective of this work, which was to perform the coupling of two computer codes for dynamic simulation, obtaining the unified code MODIACOPLA, the "pressure-surge" transient, although not strictly realistic, was satisfactorily generated and as a result, the dynamic interaction between both codes was effectively demonstrated.

It should be also considered that the simulator was made more didactic, with great power of visualization and with the ability to simulate different events.

In this work, it was also verified an extensive possibility of creating feedback modules for simulation of transients, which can be applied to more complex cases.

ACKNOWLEDGMENTS

To FACEPE for financial support;
To my colleagues from the reactor engineering group at DEN-UFPE.

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