

## A Research Reactor Simulator for Operators Training and Teaching

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### Abstract

This work describes a training simulator of Research Reactors (RR). The simulator is an interactive tool for teaching and operator training of the bases of the RR operation, reactor physics and thermal hydraulics. The Brazilian IEA-R1 RR was taken as the reference (default configuration). The implementation of the simulator consists of the modeling of the process and system (neutronics, thermal hydraulics), its numerical solution, and the implementation of the man-machine interface through visual interactive screens. The point kinetics model was used for the nuclear process and the heat and mass conservation models were used for the thermal hydraulic feed back in the average core channel. The heat exchanger and cooling tower were also modeled. The main systems were: the reactivity control system, including the automatic control, and the primary and secondary coolant systems. The Visual C++ was used to codes and graphics lay-outs. The simulator is to be used in a PC with Windows XP system. The simulator allows simulation in real time of start up, power maneuver, and shut down.

**KEYWORDS:** *Research Reactor, Training and Teaching Simulator, Reactor Operation, Operational Transient, Man-Machine Interface.*

### 1. Introduction

During the operation of a RR, the operator is on stress conditions that may affect the operation safety. [1] Training and retraining programs are established for the operating personnel, including: reactor manager, shift supervisors, reactor operators, and others working at the RR facility. [2]

In view of this concern, the International Atomic Energy Agency (IAEA) has stimulated the use of simulators at training courses in the direction of promote the better performance of the Reactor Operator. [3-7]

The development of computer-based training simulators has provided an easy understanding of reactor physics, operation, and control. In these simulators, the details are provided when necessary to describe the functionality and the interactive features of the simulator screen, which relates to the specific reactor systems. [8]

There are various types of nuclear reactor simulator and their roles in the training process are well established. [9] In general, three types are representative:

- Plant analyzer is a training device to study complicated plant transients or accidents in detail. This simulator is not required to operate in real-time nor display all actual operating data.

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- Basic principle simulator illustrate general concepts, demonstrating and displaying the fundamental physical processes of the plant. Its main goal is to help trainees understand fundamental physical processes, basic operation of complex systems, and the general operating procedures of a nuclear reactor.
- Compact simulators provide a means of training on operating procedures in a simplified form. A control desk is often provided to display significant parameters. They are powerful tools for the basic training of new operators, field operators and personnel not working in the control room. These simulators are multi-functional if provide a graphical representation of the control parameters and the operating environment.

Real-time dynamic simulators are recognized as the ultimate training tool because they allow experiencing in a dynamic mode every type of operating condition which can be encountered including start up, maneuver of power, shut down, accidents etc.

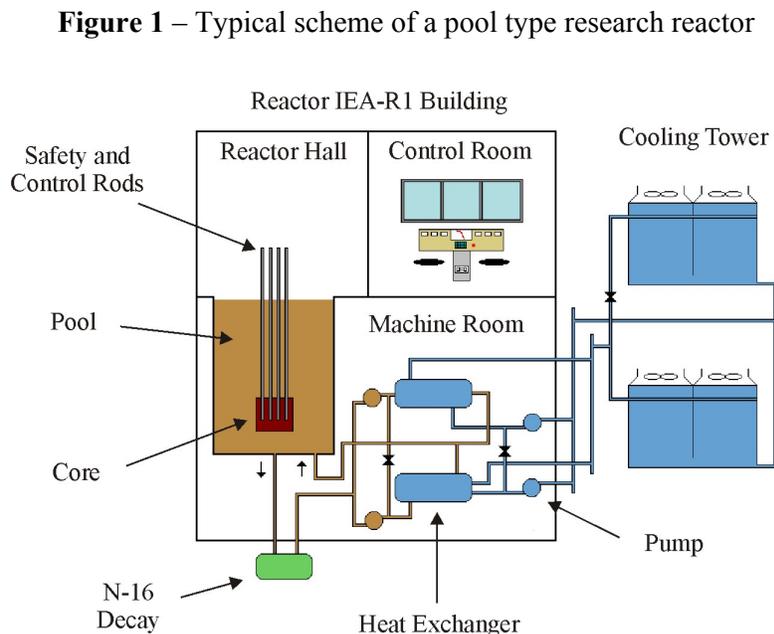
The aim of this work is describe a training simulator system for operations of RR. This system is constituted of: 1) simplified model that permit to simulate operational transients in real-time and 2) mimics and screens that permit the operator trainee to interact with the dynamic of the systems.

In general, the simulator was developed to be:

- A training platform in operations of start up, maneuvers of power, and shut down.
- A teaching tool in reactivity control, reactor cooling, and reactor protection system.
- A multi-functional simulator interactive, configurable, and educative.

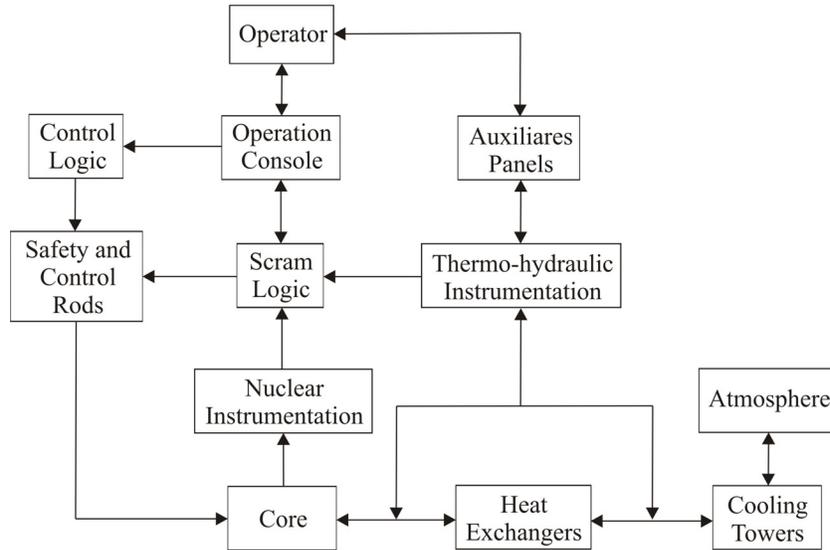
## 2. Models and Systems Overview

This session describes the identification of the systems of a pool type research reactor (RR), taking as reference the Brazilian Reactor IEA-R1. [10,11] The Fig.1 shows a schematic diagram of the main systems of the IEA-R1.



For the simulator the following systems were considered: Reactivity Control, Reactor Cooling, and Reactor Protection System. The Fig. 2 shows a simplified representation of these systems and the interaction between man-machine.

**Figure 2 – Interaction between operator and systems**



The Reactivity Control System consists of the nuclear instrumentation and its associated channels, the operation console, a manual and automatic control, and the control rods. The operator realizes operations through the operation console. In the console are available all signals of the nuclear process: Power, Log P, Period, Rods Position, N-16, Flux Control, and Safety Channel.

The neutronic mathematical model consist of the non-linear point kinetics with six groups of precursors, reactivity curves of four control and safety rods, feedback effects (xenon, samarium, and moderator, fuel, and void coefficients), and a manual and automatic control logic. The controller was modeled similar to the logic diagram of the IEA-R1. [11,12]

The reactor cooling system consists of a primary and secondary circuits. In the primary system the nuclear heat is removed by the descending coolant. The coolant transfer the heat through forced circulation for the two operational heat exchanger (plate type) which can be configured in A or B network through the adjuster of valves. The secondary system dissipates heat to the cold source (environment), through two cooling towers.

The thermal-hydraulics models are derived from the principles of conservation of mass and energy. Effects of pressure were not considered. The decay heat model was considered.

In the reactor core, the mass and conservation equations were solved by a nodal method in the average reactor plate channel. The heat exchangers were modeled as concentric tubes which flow in countercurrent. The cooling tower was modeled considering only the one-dimensional drop free fall process.

Pumps, fans, and valves modeling were considered functions step and exponential in the switch on and switch off commands.

Limiting conditions for safe operation are conditions established to ensure that there are acceptable margins between normal operating values and the safety system settings. [2,11] Tab. 1 shows the default limit conditions of operation.

**Table 1** – Default limit conditions of operation

Protection Variable	Limit (a)
Safety Channel	< 10%
Safety Channel	> 105%
Hot Leg	> 48°C
Power	> 200kW
Primary Flow	< 90%
Period	< 12 sec
HV15, HV17	Closed contact
Shim1, Shim2, Shim3, Reg	Opened contact
Scram Manual	Opened contact

(a) Conditions of shut down

The protection system is represented by a scram logic. The logic has contacts normally closed. The operator can shut down the reactor using keys in the operation console. Scram can be realized by the fall of all control and safety rods or a rod fall one by one.

### 3. Simulator Description

The Visual C++ was used to codes and graphics lay-outs. The main steps were: screens configuration, keyword configuration, Ids (identifiers) definition, objects definition, and objects orientation (objects link). In the implementation of the numerical models was considered two time variables: the PC time and time step of the numerical method.

The interaction between the user and this simulator was organized through a set of display screens and man-machine interfaces of a PC. The simulator display screens partially mimic the actual control panel instrumentation as well as provide additional instruments for analysis. Control panel devices (buttons, switches, keys) are represented as simplified pictures and are operated via panels in response to user inputs.

The simulator is to be used in a PC with Windows XP system. The simulator allows simulation in real time of start up, power maneuver, and shut down.

The pop-up menu has five options: File, Systems, Graphics, Commands, and Help. In the File option, the user can open and save files. Presently, the simulator is only running for a default configuration (IEA-R1). In the Systems option, the user can navigate by the main systems of the reactor. In the Graphics option, the user can visualize graphically the transients being simulated. In the Commands option, the user can start the simulation and adjust the simulation time. The Help option gives instruction on how to operate the simulator. The mimic environment has a personalized representation of the cooling, control, and protection systems of the default RR. In the PC keyword, the user can interact with mimics, rods, simulation time, and scram.

The Fig. 3 represents the mimic of the reactor cooling system. The user can interact directly in the mimic adjusting valves. The environment temperature can be changed and its influence in the thermal hydraulics process may be observed. The Fig. 4 represents the mimic of the reactivity control system. The user may: 1) supervise the dynamic of operation and control, 2) visualize the dynamic of the control and safety rods, and 3) observe the state of the main components of the control logic. In the center-bottom position, the user can interact with a simplified operation console, in which he interacts with the monitoring variables (power, Log P, period, N-16, rods position, reactivity, neutronic flux) and control variables (rods position, period, power).

Figure 3 – Screen of the reactor cooling system

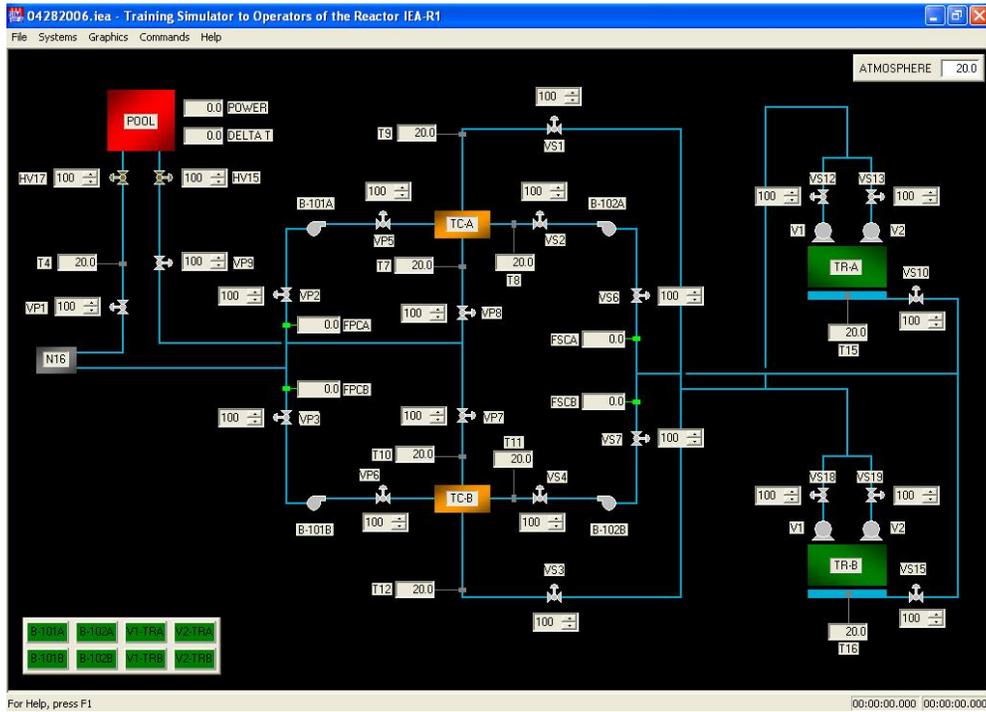
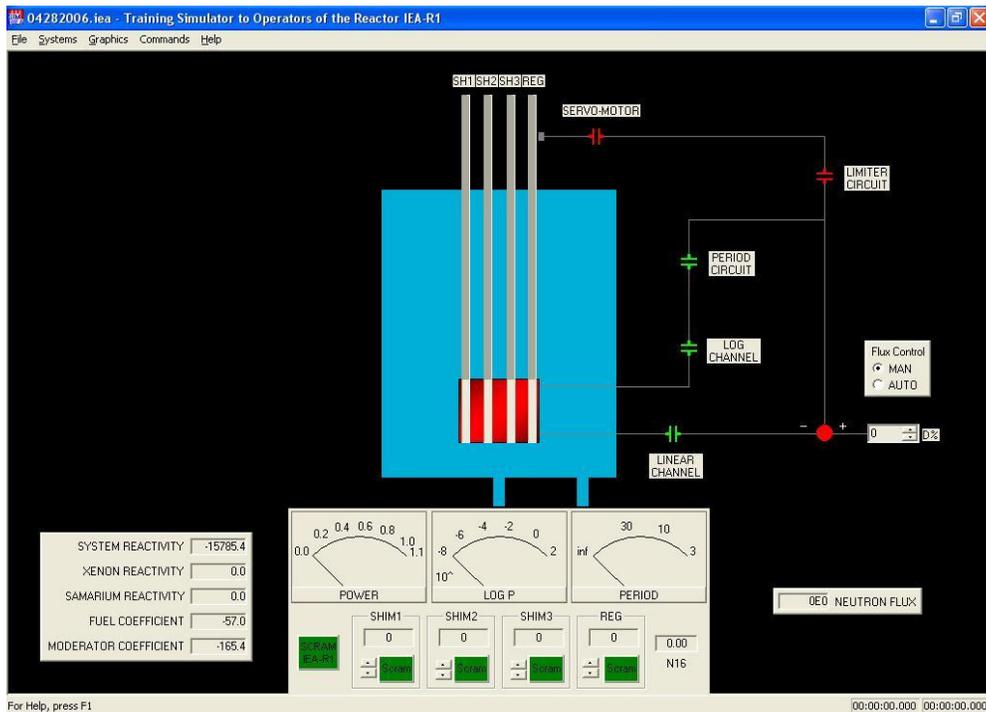


Figure 4 – Screen of the reactivity control system

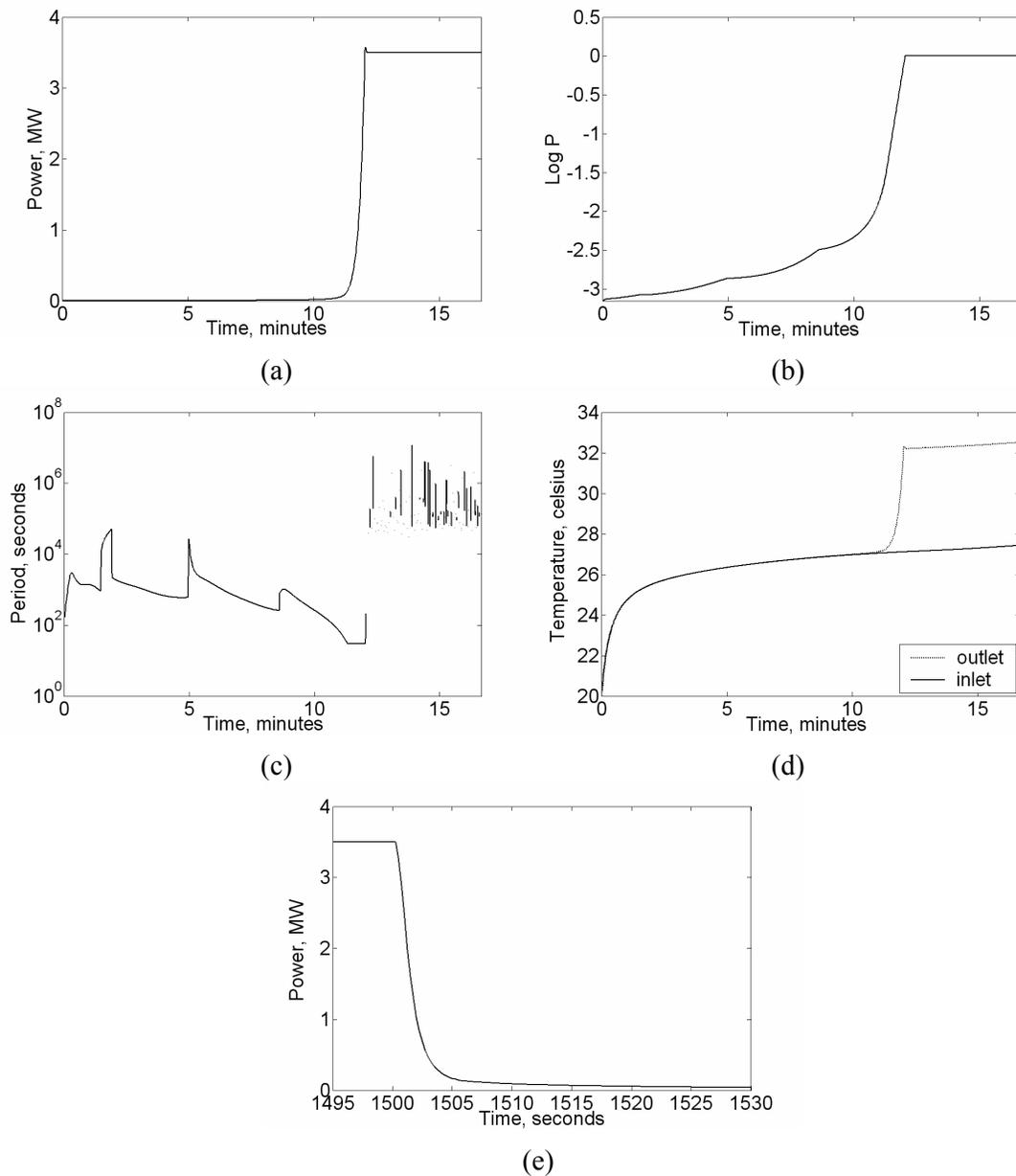


### 4. Results

To simulate the start up the control rods are moved one by one up to the reactor achieves the nominal power (3.5 MW), where the automatic control system act.

The Fig. 5.a illustrates the evolution of the power channel. In this figure the action of the automatic control can be observed by the small peak at the beginning of the nominal power platform. The Fig. 5.b e 5.c shows the Log P and Period channels, and in Fig. 5.d the temporal evolution of the inlet and outlet temperature is illustrated. In Fig. 5.e the shut down is illustrated.

**Figure 5 – Operational Transients**



## 5. Conclusions

The Simulator is being proved to be useful in teaching and training of RR operator. The main benefits and advantages are:

- The ability to train on operational transients;
- The reduction of risk to plant equipment and personnel;
- The ability to repeat a scenario as many times as necessary for trainee understanding and retention; providing training for engineering and management personnel who do not need a deep familiarity with the control room displays and instrumentation, but who need an understanding of plant processes and specific systems.

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