*2015 International Nuclear Atlantic Conference - INAC 2015*
*São Paulo, SP, Brazil, October 4-9, 2015*
*ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR - ABEN*
**ISBN: 978-85-99141-06-9**

# INTEGRATION OF COMPUTERIZED OPERATION SUPPORT SYSTEMS ON A NUCLEAR POWER PLANT ENVIRONMENT

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## ABSTRACT

Automation of certain tasks in a Nuclear Power Plant (NPP) control room is expected to result in reduced operators' mental workload, which may induce other benefits such as enhanced situation awareness and improved system performance. The final goal should be higher level of operational safety. Thus, recent works are increasingly assessing automation. The LABIHS compact NPP simulator, though, still operates under strictly manual printed hard-copy procedures, despite of the fact that the simulator incorporates several advancements in design of digitalized Human–System Interfaces (HSIs). This work presents the development, implementation and integration of selected components to achieve increased level of computerized/automated operation of the LABIHS compact NPP simulator. Specifically, we discuss three components: (i) Automatic Plant Mode Detection, (ii) Automatic Alarm Filtering, and (iii) Computerized Procedures. Each one of these components has to be carefully designed/integrated so that one can avoid the undesired effects of some known implementations of automated systems on NPP, such as the reduction in the operator's system awareness, an increase in monitoring workload, and the degradation in manual skills, which could lead to automation-induced system failures.

## 1. INTRODUCTION

Nuclear power plant (NPP) control room operators observe and manipulate an extremely complex system. In the past, this required walking along a large control panel, taking readings from gauges and adjusting knobs and levers. Many of today's control rooms have replaced or augmented older, more cumbersome control panels with visual display units (VDUs). VDUs can simplify the human machine interface, but they also introduce new design challenges. Digitalization of previous analog man-machine interfaces imposes new coordination demands on the operational teams, as the need for communication to construct situation awareness – unlike the old analog control rooms, in the new "advanced" interfaces all operators can assess almost all the information about the plant from his/her workplace [1]. This greatly increases the amount of information and tasks each operator needs to manage.

Among the tasks of an operator are the monitoring of plant status, manipulating of control devices, as well a large set of complex and mentally taxing activities, such as information gathering, planning and decision making.  In such a complex and safety-critical system, human error could result in serious accidents due to the inherently high level of complexity of interfaces, task loads, information overload, dynamic situations and annoying unnecessary/redundant alarms.

Thus, in the last decades, human-system interface of NPP has been extensively developed and improved [2,3,4,5]. One of the most assessed subjects of these improvements is the Operators' mental workload [6,7]. In general, reduced mental workload is achieved by automation of certain tasks. Automation may also induce other benefits such as enhanced situation awareness and improved system performance.

The LABIHS compact NPP simulator [8] servers a set of purposes, such as control room modernization projects, designing of operator aiding systems, providing technological expertise for graphical user interfaces (GUIs) designing; control rooms and interfaces evaluations considering both ergonomics and human factors aspect, interaction analysis in scenarios considering simulated accidents and normal operation. Fig. 1 shows the LABIHS' main control room.

**Figure 1:  Overview of the LABIHS**

This system incorporates several advances in design of digitalized Human–System Interfaces (HSIs), but it still operates under strictly manual printed hard-copy procedures. Also, neither automated plant mode indicator nor an alarm suppression system is currently available. These limitations are incompatible with the idea of modern human-system interface implementations.

This work presents the development, implementation and integration of selected components to achieve a higher level of computerized/automated operation on a specific target system: the LABIHS compact NPP simulator [8]. Specifically, we discuss three components: (i) Automatic Plant Mode Detection, (ii) Automatic Alarm Filtering, and (iii) Computerized Procedures [8].

The paper is organized as follows. Section 2 brings a brief overview of the LABIHS compact NPP simulator. In Section 3, we present the implemented automatic plant mode detection system. In Section 4 the automatic alarm suppression system is introduced. In Section 5 we assess the computerized computer procedure system. Finally, Section 6 brings conclusions and future work.

## 2. LABIHS COMPACT SIMULATOR OVERVIEW

Broadly, the simulator is composed of a set of applications that communicates between each other through a Shared Memory, as shown in Fig. 2.

The Modeling Program is the main component of the simulator. It contains all mathematical models that represent the most relevant characteristics of a pressurized water reactor power plant. The Instruction Station module allows for an instructor to interact with the ongoing simulation to provide commands according to which scenario he wants to make available to the operators.

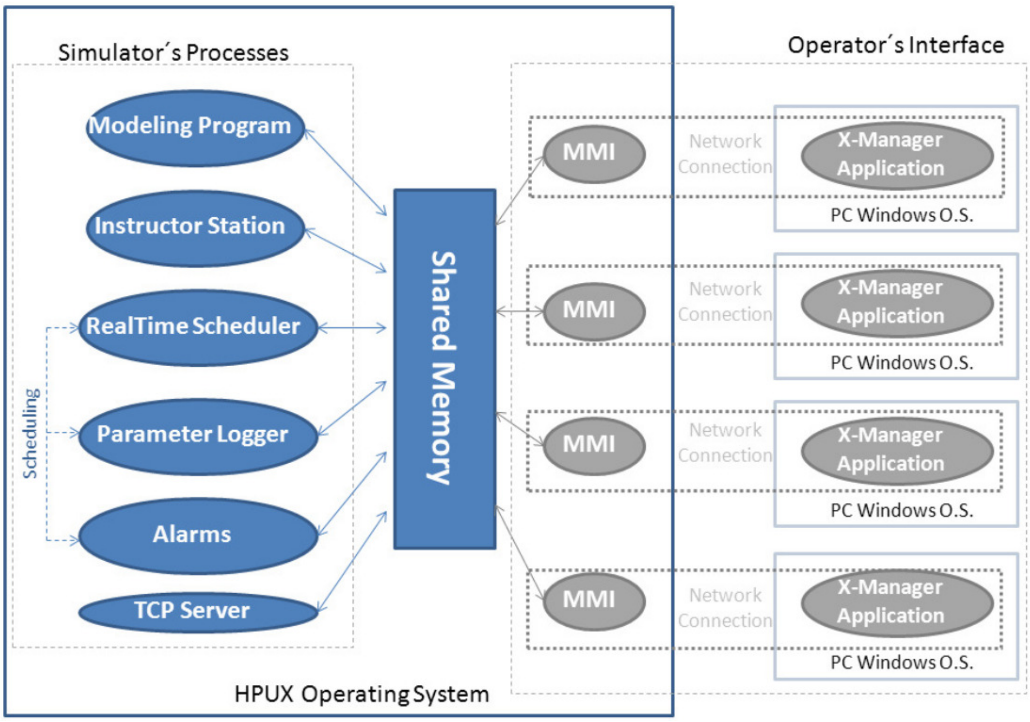


**Figure 2: LABIHS**

Three other modules provide logs and reports: RealTime Scheduler is used to set timers and schedule tasks for both Parameter Logger and Alarm List modules; the Parameter Logger module stores, into files, a set of variables describing history of past simulator states; the Alarm List module provides alarms that guide the operators during the power plant operation procedures.

The integration of all three modules (e.g. automatic plant mode detection, automatic alarm filtering, computerized procedures) assessed by this paper to the simulator is achieved by attaching each of them to the shared memory.

## 3. AUTOMATIC PLANT MODE DETECTION

The purpose of the Automatic Plant Mode Detection module is to monitor a set of neutronic/thermodynamic variables and, based on its values, decide in which operation mode the plant is currently on. The operational modes are defined as follows: (1) Refueling, (2) Cold Shutdown, (3) Hot Shutdown, (4) Standby, (5) Startup, and (6) Power Operation.

Let Keff be the reactivity condition, Tp be the percentage of the thermal power and Tcold be the average temperature of cold legs. The operational modes are defined as shown on Table 1.

**Table 1: Definition of all six operational modes**

<table>
<tr><th colspan="3">Variable Range</th><th rowspan="2">Operational Mode</th></tr>
<tr><th>Keff</th><th>Tp (%)</th><th>Tcold ()</th></tr>
<tr><td><= 0.95</td><td rowspan="4">= 0</td><td><= 57</td><td>Refueling</td></tr>
<tr><td rowspan="3">0.95 < Keff < 0.99</td><td>57 < Tcold <= 99</td><td>Cold Shutdown</td></tr>
<tr><td>99 < Tcold <= 177</td><td>Hot Shutdown</td></tr>
<tr><td rowspan="3">>= 177</td><td>Hot Standby</td></tr>
<tr><td></td><td>0 < Tp <= 5</td><td>Startup</td></tr>
<tr><td>Keff >= 0.99</td><td>> 5</td><td>Power Operation</td></tr>
</table>

Once the operational mode is known, the Automatic Plant Mode detection module writes the current operational mode to specific state variable at the simulator's shared memory, making it available to all modules (Fig. 2).

The LABIHS Graphic User Interface (GUI), then, monitors this shared memory variable and updates a Plant Mode indicator at the upper left corner of the screen, as highlighted in Fig. 4 and Fig. 5.

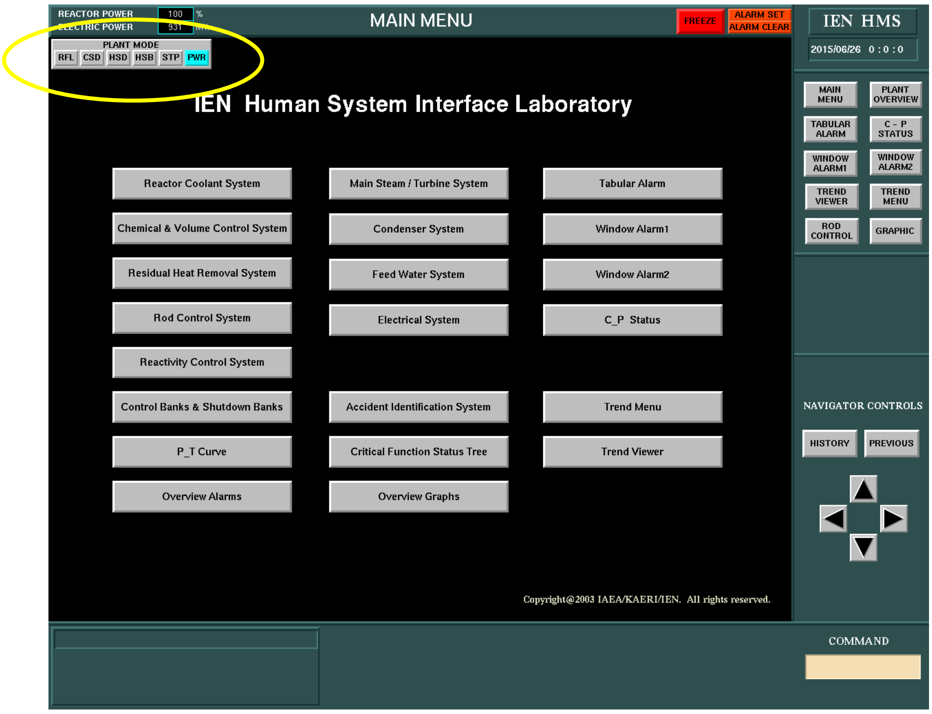


**Figure 4: LABIHS's Main Screen with the Automatic Plant Mode indicator on the upper left corner.**

The Plant Mode indicator is present on all GUI screens of the LABIHS simulator. This way, the operator is always aware of the system's current operational.

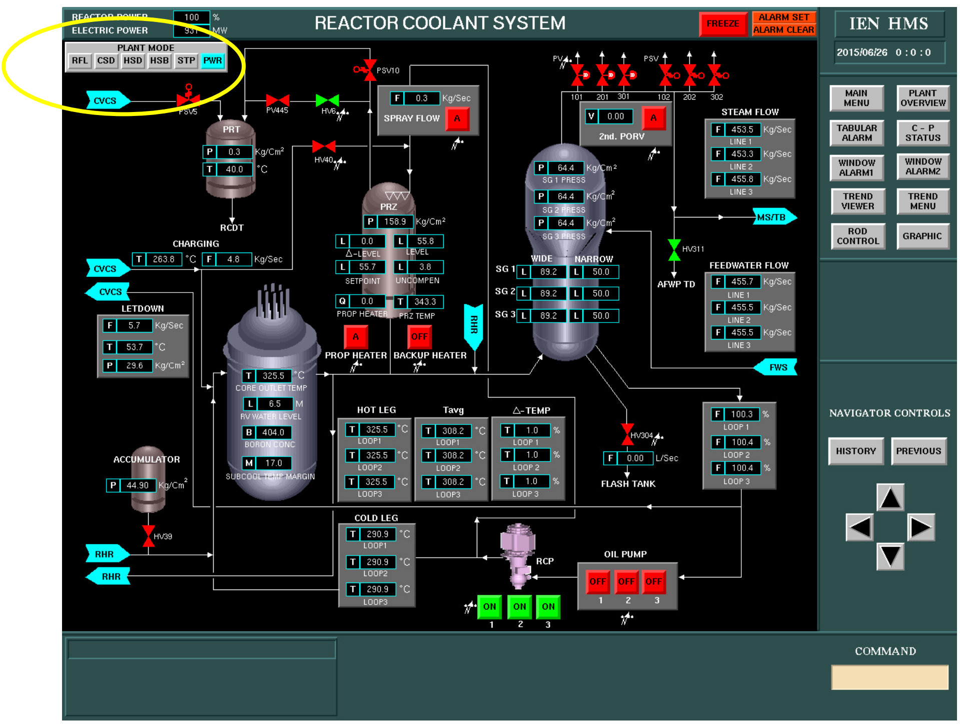


**Figure 5: LABIHS's Reactor Coolant System with the Automatic Plant Mode indicator on the upper left corner.**

## 2. AUTOMATIC ALARM FILTERING

The main purpose of the Automatic Alarm Filtering module is to suppress an unnecessary alarm based on four sources of information: Cause-Consequence, Operational Mode, Redundancy and Initializer Event.

The Cause-Consequence alarm suppression is performed when a set of alarms are enabled, but a subset of the alarms refers to consequences and not a root cause. If this is the case, then all consequences of a given cause may be suppressed.

For example, consider the selected set of alarms shown in Table 2. Suppose that the *Intermediate range high flux rod stop* alarm on the first row (alarm ID 1) is currently on (enabled). The cause-consequence column indicates that alarm ID 34 is a root cause. Then, if alarm *RCO trip intermediate range hi*, on row 34, is also enable, then *Intermediate range high flux rod stop* should be suppressed.

**Table 2: Automatic Alarm Suppression Module Overview**

| Alarm ID | On screen name | Cause-Consequence | Operational Mode | Redundancy | Initializer Event |
|---|---|---|---|---|---|
| 1 | Intermediate range hi flux rod stop | 34 | 1,2,3 | | |
| 2 | Power range overpower rod stop | 36 | 1,2,3 | | |
| 7 | CCWS outlet temp hi | | No suppression | | |
| 8 | Instrument air press lo | | No suppression | | |
| 9 | RWST water level lo-lo | | No suppression | | |
| 10 | L/D hx outlet flow lo | 16,38,39,69 | No suppression | | |
| 11 | L/D hx outlet flow hi | 12 | No suppression | | |
| 34 | Intermediate range hi flux RCT Trip | | | | |
| 42 | MSL press low si iso RCT trip | | 1,2,3 | | Yes |
| 45 | CTMT sump water level hi | | No suppression | 46 | |
| 46 | CTMT sump wter level hi-hi | | No suppression | | |

| | | | | | |
|---|---|---|---|---|---|
| 73 | MSIV trip | | 1,2,3 | | |
| 88 | TBN overspeed hi tbn trip | | 1,2,3,4 | | Yes |
| 90 | Generator break open | | 1,2,3,4,5 | | |

Another source of alarm filtering is the Operational Mode, as shown in Fig. 3.

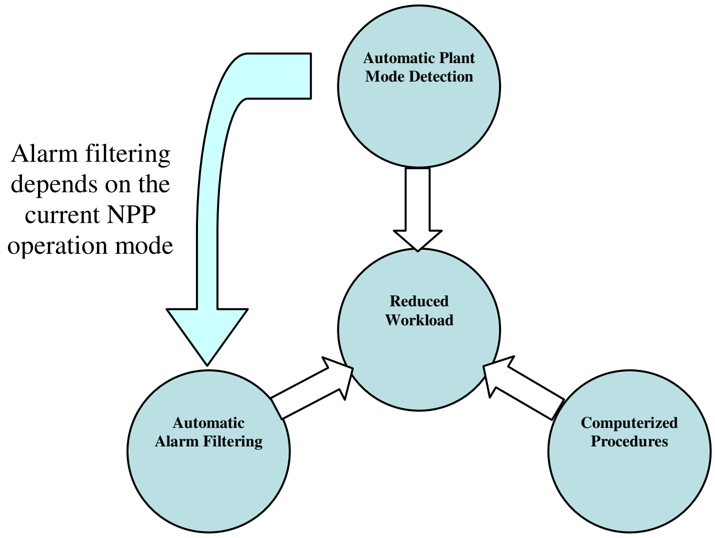


**Figure 3: How the three integrated modules contribute to workload reduction**

The basic idea of the Operational Mode alarm filtering is to suppress all non-indispensable alarms, given a given operational mode. For instance, on Alarm ID 1 of Table 2, the Operational Mode column indicates that the *Intermediate range high flux rod stop* alarm should be suppressed when the plant is on operational mode Refueling, Cold Shutdown or Hot Shutdown.

If there is no operational mode suppression for a given alarm, the *no suppression* mark is in place, as shown in alarm IDs 7 to 11 on Table 2.

The Redundancy shown on the fifth column represents the third source for alarm filtering considered. On Table 2, alarm ID 45 (*CTMT sump water level hi*) is marked, on the fifth column as redundant to alarm 46 (*CTMT sump water level hi-hi*). This means that if alarm 46 is enabled, then alarm 45 should be suppressed.

The last column of Table 2 refers to the last case of alarm filtering considered in this work: The Initializer Event. The purpose of this technique is to detect which one of several events was the first one in time to trigger. All events initiated after the first one should be suppressed.

Suppose the case in which turbine trip alarms are on, as well as the control rods trip alarm. It may take a considerable amount of time for the operator to identify which one of the two events happened in first place. The Initializer Event suppression module keeps track of a history of events. For example, if the turbine trip was the first triggered event, then the control rods trip alarm should be suppressed.

We highlight that the Initializer Event alarm filtering is at the final stages of development. What is already currently available are which events on the alarm system are bound for filtering. These events are marked with a “Yes” indication on the Initializer Event column on Table 2.

Notwithstanding, it is already clear that the Neuro-Fuzzy transient identification system developed by our workgroup [10] will be very useful to the development of the Initializer Event alarm filtering system.

## 3. COMPUTERIZED PROCEDURES

Plant operation procedures are used to guide operators in coping with normal, abnormal or emergency situations in a process control system. Historically, the plant procedures have been paper-based (PBP). The digitalization trend in these complex systems computer-based procedures (CBPs) are being developed to support procedure use.

The development and evaluation of computerized operation procedures for advanced control rooms is one of research areas of the Human-System Interface Laboratory (LABIHS) [10,11]. In [10, and [11] we developed a CBPs system in the LABIHS simulator. The ImPRO CBP [11] construction tool was chosen for our implementation because it is available for download on the Internet.

A procedure in ImPRO is decomposed into steps, and a step is decomposed into both actions and check. Both elements are connected in the flowchart. After either action or check is performed, the next action or check is ready to perform. Action has single input arrow and single output arrow, whereas check has single input arrow and double output arrows according to its evaluation. Fig. 6 shows a snapshot of ImPRO.

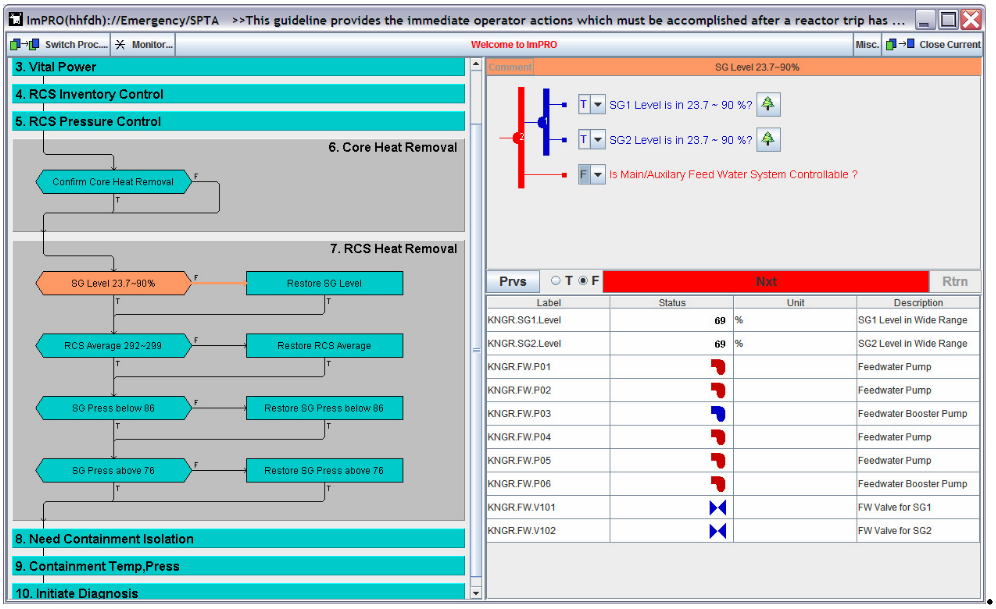


**Figure 6: ImPRO main page**

An action consists of message, set, input, finish, initiate, and caution. A check consists of auto-check, man-check, and cautions. These atomic instructions are combined to describe objective of both action and check. The binding logic is only n-out-of-m operator and can be nested. The logic is rendered in success logic tree in the right upper pane in Fig. 6.

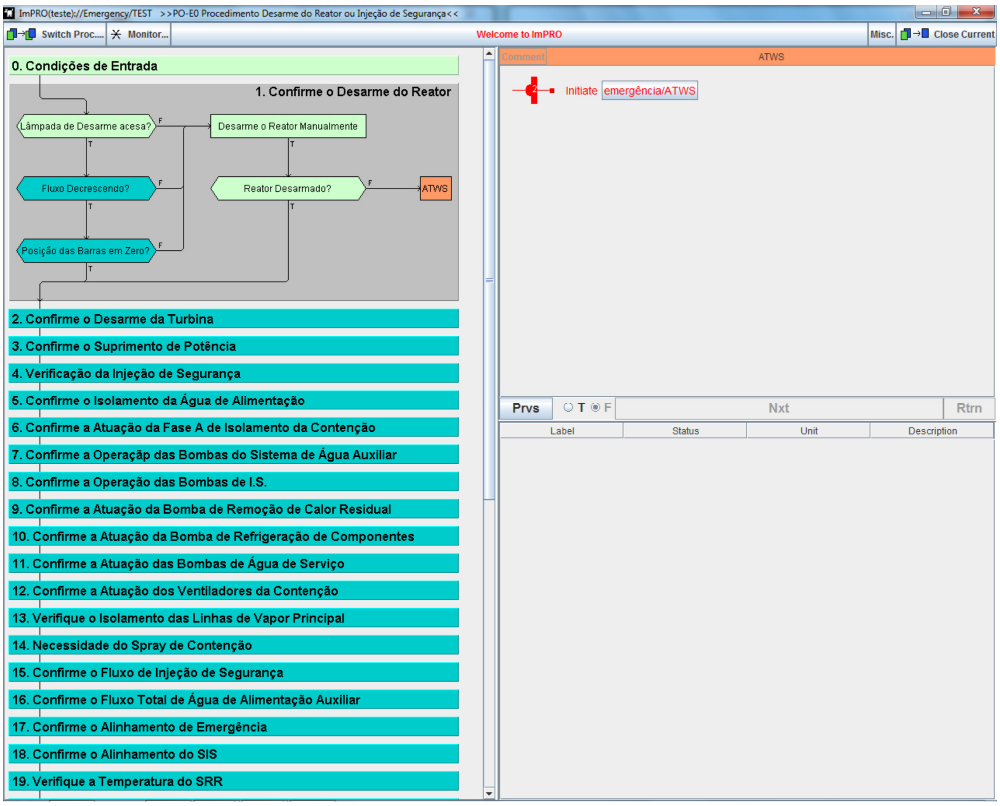


**Figure 7: Implemented CBP**

The atomic instructions have three-state value; true, false, and unknown. The value is determined by process variables. The n-out-of-m operator produces also three states. The driving force for the execution comes from crew attempt to make the current action or check resolved. After resolution, operators move to the next action or check.

The example shown in Fig. 7, illustrates a scenario in which the system is under a transient event. The operator uses a CBP and, at the end of the procedure, he was able to understand that the transient is an ATWS (Anticipated Transients Without Scram). Also, a computerized recovery procedure is provided.

## 4. CONCLUSIONS

In this work, a system based on a set of three different components was presented: (i) Automatic Plant Mode Detection, (ii) Automatic Alarm Filtering, and (iii) Computerized Procedures. The final goal of this framework is to (1) achieve a level of reduction of the operator workload during normal and emergency operations, and (2) to decrease the time necessary to identify the root causes of a transient to the LABIHS compact NPP Simulator.

The proposed framework is currently integrated LABIHS compact NPP simulator. A single module, the alarm filtering system, is at final stages of implementation and will soon be integrated.

The implemented framework was tested in the LABIHS simulator for preliminary evaluation. Evaluations were performed using typical cases of regular and emergency operations. These operations include NPP power up from the refueling operational mode to the power operational mode.

Several scenarios of operation using the alarm filtering systems were compared to the operation through the previous version of the simulator, showing advantages on the reduction on the workload as well as on the time necessary to identify/solve transients.

The next stage of this research is the completion of the initializer event system. This system must be able to further reduce workload and speed up transient detection by the operators.

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