EDUCATION AND TRAINING OF FUTURE NUCLEAR ENGINEERS THROUGH THE USE OF AN INTERACTIVE PLANT SIMULATOR

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1. Introduction

The International Atomic Energy Agency (IAEA) sponsors the development of nuclear reactor simulators for education, or arranges the supply of such simulation programs [1]. Aware of this, the Department of Nuclear Engineering of the Universidad Politécnica de Madrid was provided in 2008 with the Interactive Graphical Simulator of the Spanish nuclear power plant *José Cabrera*, whose operation ceased definitively in 2006. According with the IAEA-TEC-DOC-1411 [2] , the simulator is a Graphical Simulator, used for training of main control room personnel, technical support engineers, and operations management. This paper presents all the work performed at the Department to turn the simulator into a teaching/learning tool, to be use in the nuclear engineering studies following guidance found in [3].

2. Description of the Simulator

The experience gained in the last years by our Department in the simulation of the Nuclear Power Plants, mainly in PWR, has been included in the nuclear *Nuclear Technology* programme with optimization of manoeuvres, start-up, etc. In addition, the *Nuclear Reactor Design* programme has been focused on the understanding of the computational codes for nuclear reactor designs, starting with the nuclear data processing codes, then the core calculations codes, and finally the plant simulators codes (JANIS, NJOY, WIMSD, ORIGEN/ACAB, MCNP, COBAYA/SIMULA, COBRA, SIMTRAN, RELAP). But more realistic studies are also required to complete this general objectives, and in this sense the Simulator is the appropriate tool to be used.

The Fig.1 shows a diagram of the simulator architecture as installed in the *José Cabrera* NPP for years [4] . The Interactive Graphic Simulator SGI is the one that has been installed in the Nuclear Engineering Department, and it is an analytical graphical simulator that is especially useful for didactic purposes. It is an interactive tool, that allows the student to complete the teaching-learning methodology in the nuclear science and technology with more practical methodologies, as is recommended in the new engineering studies adapted to the Bologna rules.

The components and systems of the whole power plant are replicated in the Simulator, this includes the nuclear reactor, the pressurized vessel, the primary and secondary loops, the turbine, the condensator, the fluids systems, the instrumentation and control components, and the electrical systems, as well as the emergency systems that are automatic started when needed. Also the simulator has an alarm panel that provides information similar to the one provided in the power plant, showing the variables and parameters that are out of range, and shows if the operator has to take any action, or at less helps to identify the variables.

The alarm panel is divided in three panels: primary circuit, secondary circuit, and post-accident conditions. The software is supported in a HP-735 workstation, and three SUN SPARC 4 Work Station. The screens allow to click in a component and get the information in a graphical way. Fig.2 shows the SGI work stations and alarm panels as they are installed in the Department.
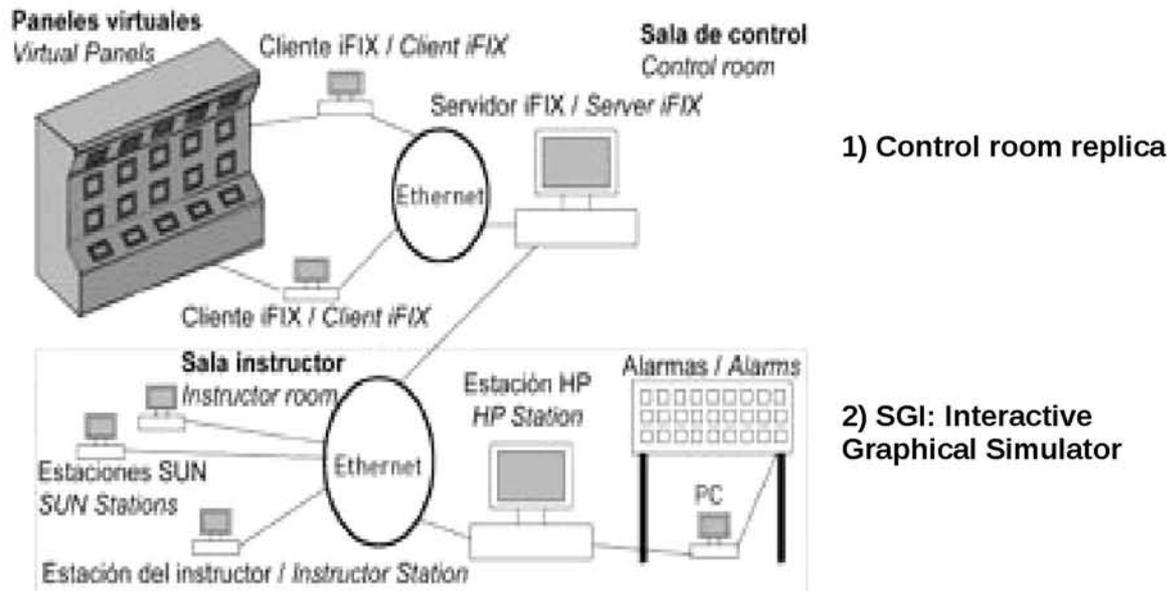

Fig 1. *José Cabrera* **Nuclear power plant General Simulator Arrangement**

The components are represented in different screens with diagrams where the different colours indicates the status of the component (open/close, on/off,…). The functions available are: Initialization with until 60 different initial conditions, run/stop the simulation, malfuctions with different severity and duration, function SPDS with a continuous showing of the safety parameters, and the graphic representation.

The nuclear power plant of origin was a PWR reactor with only one primary circuit. This makes the installation simpler in order to be used for teaching purposes, that other nuclear plants with 3 or 4 primary circuits.

The simulator provides the real plant responses and the physical behaviour during the normal operation, and simulates several maneuvers, a series of malfunctions, and operational transients, and also allows the training in the emergency procedures under accident situations. With the simulation of these situations the student is trained in the plant behaviour, and in the nuclear and thermohydraulic phenomenology in the nuclear reactor and in the components of the whole plant. For that purposes includes the TRAC-PWR and RELAP5/MOD3.2 codes as the software package, that simulates the whole plant behaviour.

Very illustrative screens, as the one in Fig.3, show all the plant systems, and allow to act directly on the system components. Alarm control panels, similar to the ones existing in the control room of a nuclear power plant, are also available to alert users of potential equipment problems or unusual conditions.

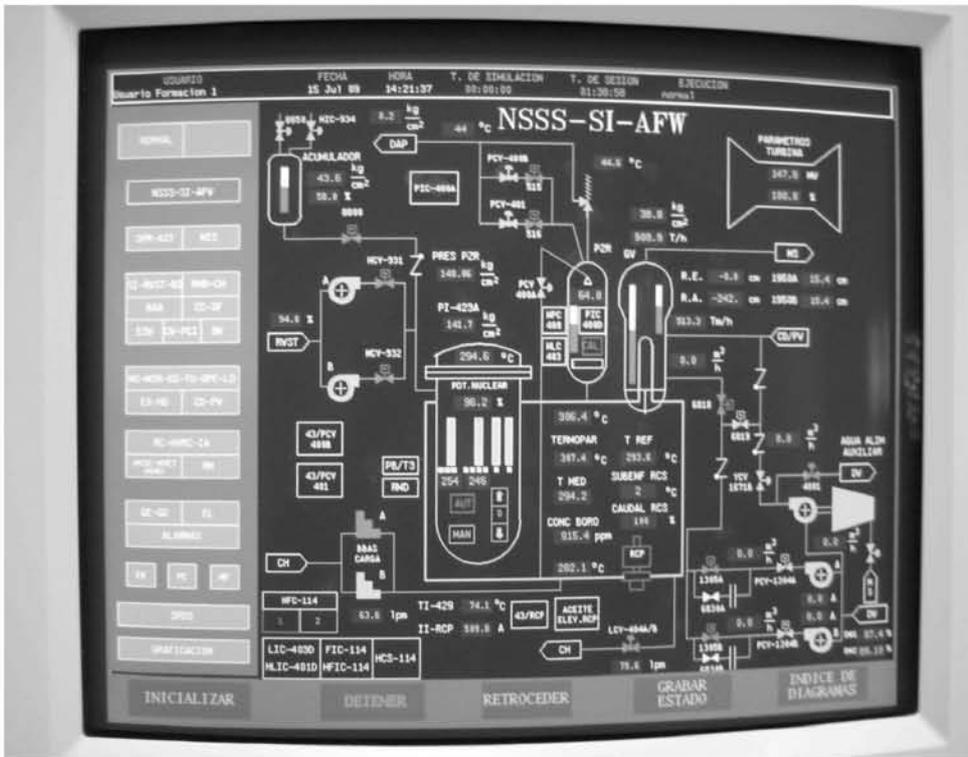**Fig 2. Aula *José Cabrera* with the Interactive Graphical Simulator (SGI)**

Fig 3. One Screen with reactor vessel, injection system, and auxiliar feedwater system

3. Methodology

The Nuclear Engineering Department dedicates two technicians to be responsible of the installation, one for the hardware and equipment, and other for the use of the simulator, and the students assistance. The Department has also the support of the Gas Natural - Union Fenosa company through the assistance of the technician who was the power plant operator trainer in the *José Cabrera* power plant, in order to solve the doubts and problems that may appear during the use of the installation. Also the Tecnatom company that developed the whole installation assist in order to solve punctual hardware and software problems.

A Commission integrated by members of the Nuclear Engineering Department (2 persons) and the Gas Natural - Union Fenosa company (2 persons), has been created to follow the work performed in the Simulator, and make proposals to improve when necessary, the teaching-learning process.

Aware of the advantages that the use of a simulator as SGI can provide for an active and independent training of our students, different material is under preparation for the development of practical classes. The aim is to provide students with the tools necessary to be able to acquire, following an active methodology, scientific knowledge and technology related to the design, safety and economical operation of a nuclear power plant. The intention is to encourage the student giving him a greater role in their learning, by providing a virtual environment that allows to operate the plant as if an operator is involved.

In the preparation of this material contribute teachers and technical staff of the Department as well as students who are in different stages of their studies.

Three types of students can be described regarding the use of the simulator:

- Undergraduate students that use the Simulator for the practices period of the topics that are part of the Grade level curricula: *Nuclear Power Plants, Nuclear Technology, and Nuclear Safety.*
- Master degree students that work for a period of 6 months in the Simulator, normally supported by a fellowship of the Consejo de Seguridad Nuclear (CSN, the Spanish nuclear regulatory commission), and develop the Master Final Project in the Simulator. This project provides 15 ECTS (European Credit Transfer System) for the *"Nuclear Science and Technology Master"*. Also the Industrial Engineering Master Final Project may be carried out in the Simulator.
- Visiting and collaborating students that spend part of their time learning the use of the simulator and afterwards helping in the development of the material needed for its productive used from the Teaching-Learning objective point of view. The first ones are coming from foreign universities, the second ones are students from the Naval and Industrial Engineering Schools.

The graduate students that use the Simulator should start with the identification and understanding of the existing documentation, and then they may contribute providing more detailed documentation, description of the screens and components, or simulation of different situations. They generate the related documentation with the analysis of the results that have been obtained. Also they may prepare standard and simple practices to be run by the undergraduate students during the teaching-learning period at the grade level studies. Each student has a tutor or director of the project, which analyze the developed material, in order to help, guide and evaluate the student during the learning period.

The students have access to the manuals that the power plant operators have used in the continuous training they have followed [5,6], and the Nuclear Regulatory Commission in Spain demand. The documentation includes the description of the power plant systems, the emergency operation procedures, as well as the description of the Simulator, the initial conditions available, and the malfunctions that may be simulated.

The material that is being prepared for each class or group of classes that constitute a practice for the undergraduate students is divided into three parts according to their purpose in the development of work by the student. These are:

- Practice Manual: objectives and theoretical basis, systems involved in the maneuver and main variables to be monitored, guide implementation of the maneuver, with detailed actions that students must carry out.
- Monitoring material, that the student must complete during the practice: tables for data collection, graphical representation of the temporal evolution of the significant variables, graphical analysis.
- Material self-assessment that the student must complete following the practice: issues related to the development of practical and theoretical foundations.

4. Main results and experience

The standard operational situations that have been prepared for the moment and run by the students are:

- Normal operation in nominal power.
- Nuclear power variations and turbine demand follow.
- Identification of the operational states in the plant: Cold-Zero-Power, Hot-Zero-Power, Hot-Full-Power, Nominal operation.
- Plant start-up, from Cold-Zero-Power to Full-Power.
- Plant down, from Full-Power to Cold-Zero-Power, and evolution during the Zero-Power period.

The simulator also allows the simulation in hypothetical accidents, those which are complex and with a very low probability to happen. This is used in the training, in order to understand the optimal way to drive the plant to an stable and safe situation. For the simulation of the accidents, the best-estimate and realistic codes are used. Codes that have been validated previously. The evolution is done in real time, reason why the student take conscience of the time and the risk of these potential situations, and the high reliability needed in order to limit the global risk.

These accidental and complex situations provide the student the detailed understanding of the head transmission and fluids mechanics, the kinetic reactor behaviour and the coupling among them. These situations are for the moment under testing. They should be carried out by the students when the simpler transients and maneuvers are completely understood .

The accident situations are very extend, and as a sample may be simulated the following:

- Loss of electric feed, with failure of external electrical feed and Diesel Generator.
- Steam generator tube break, with or without the safety injection system.
- Reactor scram signal with failure in the control rod insertion, and success boration.
- Main pump rotor stop, with pressurizer valves opening.
- Small LOCA with safety injection, 0,5" primary circuit break.
- Essential services water loss, and auxiliary feed-water system.

- Components cooling system loss, and auxiliary feed-water system.
- Main steam line break in the auxiliary building, with safety injection system failure.

Until now several projects have been performed by the postgraduate students, under four Collaboration fellowships, and three Master Final Projects, covering the following topics:

- Preparation of the SGI Documentation and User's Manual (systems descriptions, transient and operational modes, systems identification, screens and alarm panel description)
- Preparation of the SGI Malfuctions Manual (in particular for the Loss of coolant accident)
- Transient analysis due to primary circuit changes (Simulation of Loss of coolant accident in cold leg, user's guide preparation, analysis of the Emergency Operation Procedures)
- Transient analysis due to malfuctions in the valves (pressurizer shower valve, pressurizer relief valve)
- Optimized Plant Start-up and Initial conditions.
- Optimized Plant down and drive to the cold conditions. Identification of the Xenon peak during the stop period.
- Loss of coolant accident simulation with a guillotine break in the cold leg.

And the practices programmed for the undergraduate students until now have been the following:

- *Nuclear Power Plants*, with 50 students: Nominal operation simulation, and thermal power variation simulation
- *Nuclear Safety* with 40 students: Loss of coolant accident simulation

For these practices the students have the Practice Guide Manual, and as a sample the following documentation is available for the *Nuclear Safety* practice [7] : Practice Manual (description of the practice, systems involved, and variables to follow, and realization guide), Follow-up material (Tables to feel-up, Graphic representations to prepare), and auto-evaluation material (questions to answer).

The students are trained through the simulations in the interpretation of the screens that are showed in the workstations, and the plotted variables and its temporal evolution. The adviser professor examines the results obtained by students in order to assess if the simulation has been effective.

5. Conclusions

The experience obtained so far with the use of the simulator has been very successful. The graduate students involved in the development of the projects, practices and documents related with the simulator show a great interest for the work that they are doing making that the laboratory where the simulator is installed to be busy place. Regarding the undergraduate students, the practices in the simulator encourage them to follow the Nuclear Energy studies in the Engineering Schools, what is very rewarding for the Department professors.

The simulator has proved to be an optimal tool to transfer the knowledge of the physical phenomena that are involved in the nuclear power plants, from the nuclear reactor to the whole set of systems and equipments on a nuclear power plant. It is also a relevant tool for motivation of the students, and to complete the theoretical lessons. This use of the simulator

in the learning-teaching process meats also the criteria recommended for the Bologna adapted studies, as it helps to increase the private hands-on work of the student, and allows them to experience the work inside a team, in a practical and real installation.

It should be noticed that this type of simulator is only available in selected universities and Nuclear Engineering Departments in the world, and that it helps to reach the excellence in the nuclear engineering programs studies.

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