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Education and Training of Future Nuclear Engineers Through the use of an Interactive Plant Simulator*

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The successful experience of the Jose Cabrera Nuclear Power Plant Interactive Graphical Simulator implementation in the Nuclear Engineering Department in the Universidad Politécnica de Madrid, for the Education and Training of nuclear engineers is shown in this paper. The paper starts with the objectives and the description of the Simulator Aula, and the methodology of work following the recommendations of the IAEA for the use of nuclear reactor simulators for education. The practices and material prepared for the students, as well as the operational and accident situations simulated are provided.

Keywords: nuclear power plants; interactive simulator; education and training

1. Introduction

Computer simulators are becoming a fundamental tool for education and training in many engineering fields. In the nuclear industry, the role of simulation in the teaching on nuclear power plants operation is also recognized of the utmost relevance. As an example, 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. It is a full scope simulator running in real-time, used during the commercial operation of this power plant for operators training and examination.

According with the IAEA-TECDOC-1411 [2], the simulator is a Graphical Simulator, used for training of Main control room personnel, Technical Support Engineers, and Operations Management. It is able to analyze and understand plant dynamics, to develop skills, and to validate procedures.

The simulator provides the plant responses during normal operation and hypothetical accident situations. Very illustrative screens 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.

This simulator can play an important role in the education of our students in the nuclear technology field, since it provides a very attractive virtual space that allows students to explore and operate a nuclear power plant, improving the understanding of how the whole system works. On one hand, we hope to attract, motivate and retain students within the nuclear science. On the other hand, we want to improve the quality of the education, making students more active in their own learning and replacing simple memorization of the complex processes involved in the operation of a nuclear power plant by a more meaningful learning, by an interactive and team working experience.

However, since the simulator has been designed for operator training, multiple activities have being carried out before it was able to be used for effective engineering educational purposes. As an example, taking into account that many operational manoeuvres in a nuclear power plant can take several hours or even days, and the simulator works in real time, it has been necessary to prepare different initial conditions that allow students to reach the sequential intermediate states of the manoeuvre without running the complete real-time simulation.

This paper presents all the work performed at the Department to turn the simulator into a teaching/learning tool, following guidance found in [3]. First, the methodological aspects of simulations are discussed. Then, the developed material to help, guide and evaluate the student during the learning process is presented. Some examples of operational manoeuvres simulations are given. Finally, we examine the results obtained by students in order to assess if

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the simulation has been effective. With the obtained experience, we analyze the advantages and disadvantages of training simulators for educational purposes, identifying limitations and concluding guidelines to make this kind of simulators an adequate tool for education.

2. Teaching-learning objectives

The present nuclear technology programme implemented in the Nuclear Engineering Department, named Plan'2000, was approved by the Spanish Ministry of Education, and it has been based on an extended revision of the previous Plan'1976 on the nuclear technology programme. An extensive work was performed to improve the following subjects in the curricula: *Nuclear Power Plants, Nuclear Technology I and II, Nuclear Safety, and Nuclear Reactor Design.*

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 Technology II* 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).

Although these new developments have been well received from Teaching-Learning Objectives point of view by the students, 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 Programs for the engineering studies adapted to the Bologna rules, should include more practical teaching-learning methologies, in this sense the Simulator is a perfect tool to cover this new need.

3. Description of the simulator

The simulator installed in the Nuclear Engineering Department includes the hardware and the software that have been used in a José Cabrera nuclear power plant for years [4], that is a Interactive Graphical Simulator (SGI), which includes the TRAC and RELAP5 codes as the software package, and simulates the Pressurized Water Reactor (PWR) physical behaviour under operational and accident situations.

Figure 1 shows a diagram of the simulator architecture as installed in José Cabrera NPP. The simulator admits in the power plant two differentiated types of operation:

1. Operation in virtual panel mode (full scope simulator). Similar to the control room replica but with virtual panels. When the virtual panel operating mode is selected, the simulation models are put into communication with the screens that represent instrumentation.
2. Operation in interactive graphic simulator mode (SGI, analytical graphical simulator). In this case, the virtual panels do not start up and operation is developed through graphic stations (SUN stations) composed of simplified schemes of the plant's component systems. In these schemes, known as sheets, the operator can ascertain the status of pumps, switches or valves via a colour code, read the instrumentation status via the available indicators, and interact with the simulation through simplified representations of mouse-operated levers or controllers.

This operating modality of the simulator will

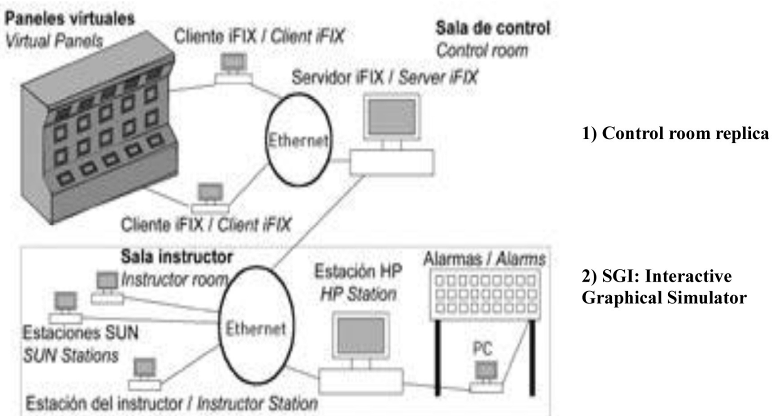

Fig. 1. José Cabrera Nuclear power plant General Simulator Arrangement.

likely be more advisable on occasions when didactic criteria are involved or will be more convenient when engineering analyses are being carried out.

The simulation engine in both cases is the same, and it is executed on the same machine, i.e. an HP station.

As seen in Fig. 1, the simulator configuration involves the use of two networks (Ethernet). The first network contains the HP station, simulation model support, instructor station and graphic stations described above. The second network contains the PCs that act as clients and support the virtual panel screens.

As part of the model extension, code RELAP5/MOD3.2 has also been included in the simulator (although not with real-time requirements), as an alternative to the normal neutronic/thermo-hydraulic model TRAC-PWR. In this way, the simulator is fit for use in studies and analyses by basically using the same model as the one used in engineering calculations.

The simulator was installed in José Cabrera NPP since the second quarter of 2002 and it has already been used for different purposes until the close of the power plant in 2006. Since the beginning of the installation process, the plant's Operations Division has actively taken part in the comments and suggestions.

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 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.

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

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. Figure 2 shows the SGI work stations and alarm panels as they are installed in the Department.

The components are represented in different screens with diagrams where the different colours indicate the status of the component (open/close, on/off, . . .).

The functions available are: Initialization with until 60 different initial conditions, run/stop the simulation, malfunctions 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 is the *José Cabrera* nuclear power plant that is 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 during the normal operation, and simulates several manoeuvres, a series of malfunctions, and operational transients, and also allow the training in the emergency procedures. With the simulation of these situations the student is trained in the plant behaviour, and in the nuclear and thermo-hydraulic phenomenology in the nuclear reactor and in the components of the whole plant.

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.

4. Benefits of simulators use

Concerning the initial use of the simulator outside the university environment, the initial training programmes in a nuclear power plant are established

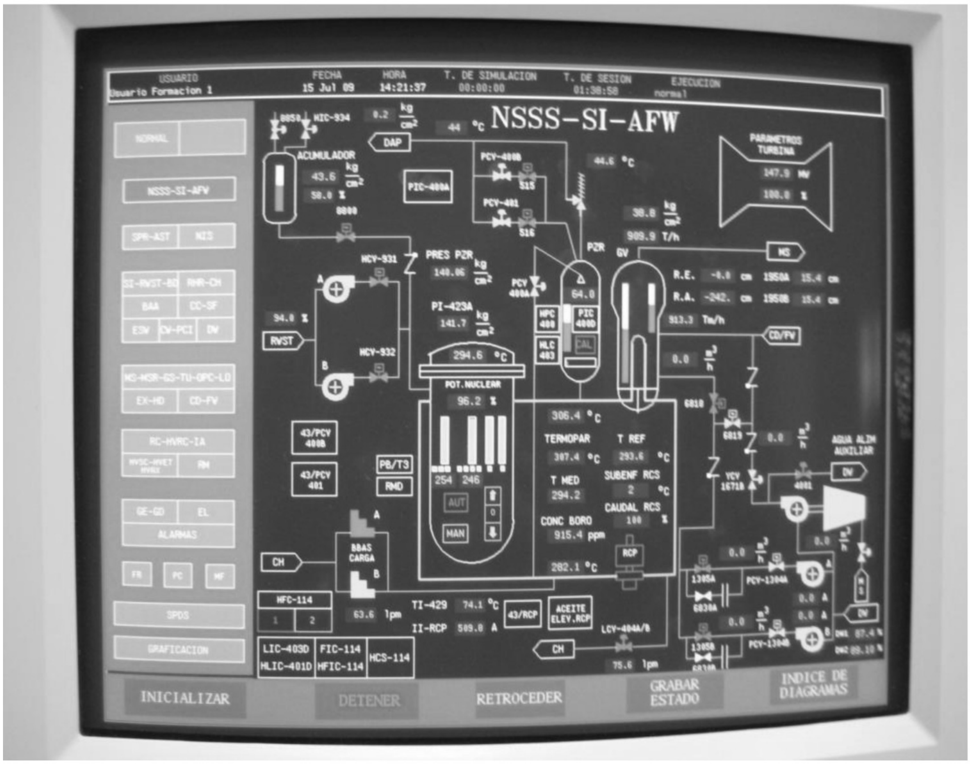

Fig. 3. One Screen with reactor vessel, injection system, and auxiliar feedwater system.

for control room personnel to develop their knowledge and skills to operate the plant safety and reliably. These programmes are structured according to each individual's specific control room operating or supervisory position. The initial training usually begins with classroom training on fundamentals and theoretical training followed by training on systems, components, and plant equipment.

During this training the simulator is first used to familiarize the trainee with plant instrumentation and control locations in the control room, followed by demonstrations of the operation of systems and components. Simulator training exercises then usually begin with instructor demonstrated and coached exercises that involve normal reactor startup and shutdown, and the introduction of progressively more complex malfunctions to develop the skills and confidence of the trainees. These initial training exercises emphasize the importance of the use of plant procedures and provide practice in the diagnosis, as individuals, of problems.

As operators gain experience, exercises are introduced involving integrated plant operations and incorporate multiple malfunctions with emphasis on teamwork and communications to diagnose problems, and for the team to safely operate the plant and mitigate abnormal and emergency events using plant procedures and operating limits.

Considering simulator training as an integral part of overall training programmes for specific jobs, this type of training is used to reinforce learning objectives taught in other settings such as the classroom and vice versa. It has also been recognized that full-scope, plant referenced control room simulators are not universally the best tool to achieve some training objectives assigned to simulator training. For example, for initial operator training, simplified, graphical simulators can be more effective in helping trainees to understand nuclear reactor and thermodynamic principles. Similarly, simulators that help operators and control room teams to 'see inside' the reactor vessel and steam generators have proven more effective than full-scope simulators in understanding thermo-hydraulic phenomena during accident conditions.

Furthermore, analytical simulators with more robust thermodynamic models of the reactor core can provide better training tools for emergency response and engineering personnel than the more limited models used for full scope simulators.

Then analytical graphical simulators are especially interesting for a Teaching-Learning program for engineers in the nuclear science and technology involved in a nuclear power plant operation. This was one of the reasons why the SGI has interest to be installed in the Department without the use of the control room replica that was discarded.

Training programmes for control room personnel typically consist of a combination of classroom, on the job training, simulator training, and self-study. The objectives of the training are to equip control room operations personnel with the knowledge, skills, and abilities necessary to operate the plant in a manner that is safe, reliable, and professional.

For control room operators, most operating organizations use job and task analysis (or job competency analysis) to determine the content of simulator training. This analysis identifies tasks to be included in both initial and continuing simulator training. The analysis also ensures that performance standards are developed and used for critical tasks and critical task elements (steps). Operating experience is also an important source for identifying simulator training needs. Irrespective of the methods used to analyze the training needs, the involvement of subject matter experts in the analysis process is essential.

A simulator provides the most realistic 'hands-on' tool for the training of control room personnel on the manipulation of plant controls during normal operation and in particular for postulated transient and accident conditions.

Collectively, these goals and objectives provide emphasis on training on:

- Individual components, equipment, and systems
- Normal startup, operation, and shutdown
- Response to plant transient, abnormal, and emergencies
- Plant and industry operating experience
- Re-enforcement of theory and fundamentals; teamwork, communications, and diagnostics

5. Methodology

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 are contributing significantly teachers and technical staff of the Department as well as students who are in different stages of their studies.

5.1 Students

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

1. 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.
2. 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.*
3. 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, where the Department professors are teaching, that are interested in the Simulator. The last ones are also supported by CSN fellowships.

The graduate students that use the Simulator should start with the identification and understanding of the existing documentation, and they may contribute them 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 the graduate student 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 has 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.

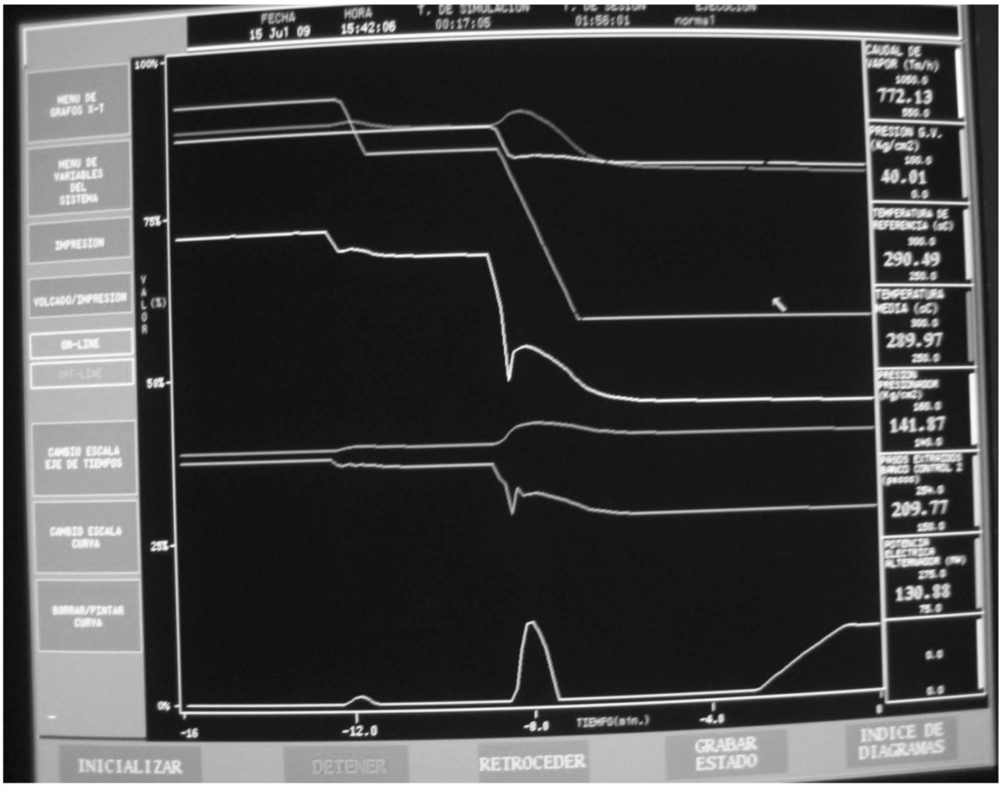

Fig. 4. One scheme with graphics provided by the Simulator.

5.2 Material

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, comprising:

- objectives and theoretical foundations of practice.
- systems involved in the manoeuvre and main variables to be monitored for follow-up (so, thereby limiting the number of screens that the student needs to consult).
- guide implementation of the manoeuvre, with detailed actions that students must carry out, given the large number of phenomena that occur.

Monitoring material that the student must complete during the conduct of the practice:

- tables for data collection.
- graphical representation of the temporal evolution of the significant variables (Fig. 4).
- if appropriate, graphical analysis, in an outline provided to students (Fig. 5), of the systems involved.

Material self-assessment that the student must complete following the completion of practice:

- issues related to the development of practical and theoretical foundations.

6. Main results

6.1 Operational Situations

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 a stable and safe situation.

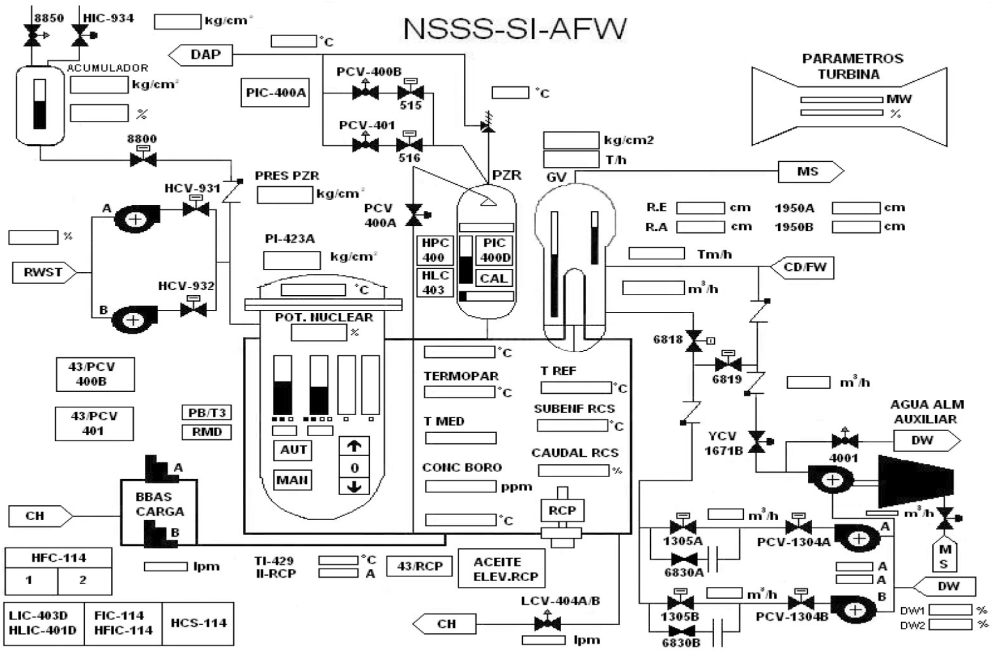

Fig. 5. One scheme provided to the students with the systems diagram.

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 takes 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 (loss of coolant accident (LOCA), steam generator leak, main pump rotor stopped, transients with the protection system failure and the reactor scram, etc.) 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 manoeuvres are completely understood.

6.2 Accident situations

The accident situations to be simulated are:

- 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.
- Loss of the air supply in the instrumentation system.

6.3 Scenarios in the Simulator

The typical list of scenarios to be performed on a Simulator for a Nuclear Reactor are:

- Plant or reactor startups to include a range that reactivity feedback rate is established.
- Plant shutdown.
- Manual control of steam generators or feedwater or both during startup and shutdown.
- Boration or dilution during power operation
- Significant (more than10 percent) power changes in manual rod control or recirculation flow.
- Reactor power change of 10 percent or greater.
- Loss of coolant, including:
  - Significant PWR steam generator leaks
  - Inside and outside primary containment
  - Large and small, including leak-rate determination
  - Saturated reactor coolant response (PWR)
- Loss of instrument air (if simulated plant specific)
- Loss of electrical power (or degraded power sources)
- Loss of core coolant flow/natural circulation.
- Loss of feedwater (normal and emergency).

- Loss of service water, if required for safety.
- Loss of decay heat removal cooling.
- Loss of component cooling system or cooling to an individual component.
- Loss of normal feedwater or normal feedwater system failure.
- Loss of condenser vacuum.
- Loss of protective system channel.
- Mis-positioned control rod or rods (or rod drops).
- Inability to drive control rods.
- Conditions requiring use of emergency boration or standby liquid control system.
- Fuel cladding failure causing high activity in reactor coolant or offgas.
- Turbine or generator trip.
- Malfunction of an automatic control system that affects reactivity.
- Malfunction of reactor coolant pressure/volume control system.
- Reactor trip.
- Main steam line break (inside or outside containment).
- Instrument failures (e.g. nuclear instruments)
- Anticipated Transient Without Scram (ATWS).
- Multiple safety system failures
- Annunciator failures during both normal and emergency evolutions

All of them are able to be performed and will form part of the future program for the students.

6.4 Projects performed

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

- SGI Documentation and User's Manual (systems descriptions, transient and operational modes, systems identification, screens and alarm panel description)
- SGI Malfunctions 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 malfunctions 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.

6.5 Practices for students

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

Topic *Nuclear Power Plants*, with 50 students:

1. Nominal operation simulation.
2. Thermal power variation simulation.

Topic *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).

6.6 Run time in the simulations

The Simulator runs in the real time as in the nuclear power plant, then the running time depends of the simulation to be run.

For the practices of undergraduate students a simulation of few hours is chosen.

The ECTS assigned for that practices varies from 0, 5 to 1 ECTS, depending of the simulation run.

6.7 Dedication in implementing the simulator

Initially the implementation of the Simulator was done by electrical technicians, and the software implementation by experts of the nuclear power plant, devoted to that task.

After that the professors and assistance of the Nuclear Engineering Department attended a training course of a week duration in order to learn the practical use of the Simulator.

The Nuclear Engineering Department dedicates two technicians to be responsible of the installation, one for the hardware and equipment, and other of 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 us in order to solve the hardware and software problems.

A Commission integrated by members of the Nuclear Engineering Department (2 persons) and 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.

6.8 Objective surveys and knowledge evolution

The students fill a test before the practice and the practice in order to check the evolution in the knowledge after the Simulator use.

The professors take into account the results obtained in the test, and also in the Follow-up material they have to fill after.

In general the evolution in the knowledge is very positive, because they get a better understanding of the classes explanations.

7. Experience on student learning

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.

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.

8. Conclusions and future work

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 the best universities and Nuclear Engineering Departments in the world, and that it helps to reach the excellence in the nuclear engineering programs studies.

With the use of the simulator in the Universidad Politécnica de Madrid during the past 2 years, some limitations have been identified, and it has been concluded that several guidelines are needed to make this kind of simulators an adequate tool for education. Some of them have been already prepared by the Master Degree students [8–9], and some other are under preparation.

For the future the Simulator exercise guides (SEG) should be developed, that are the 'lesson plans' for conducting training on a simulator and that are commonly used in the operators training in simulators. They are the documents that govern the implementation of scenarios and contain an outline of the sequence of events as well as the training objectives for the scenario. They also serve as the lesson plan for pre-simulator briefings; otherwise a separate lesson plan may be used.

Appendix

Simulator Guide Content

The typical Simulator Exercise Guide Content is:

- Title
- Number Code
- Effective date

References

1. *IAEA Activities in Nuclear Reactor Simulation for Educational Purposes*, R. B. Lyon, International Atomic Energy Agency, Vienna, Austria, April, 2000.
2. Use of control room simulators for training of nuclear power plant personnel, September 2004, IAEA-TECDOC-1411.
3. A. Shtub, T. Parush and T. Hewett, The use of simulation in learning and teaching, *Int. J. Eng. Educ.*, **25**(2), 2009, pp. 206–208.
4. F. Merino, J. Blanco, et al, New simulator for José Cabrera Nuclear Power Plant, *Revista de la SNE*, **224**, 2002, and L. Rebollo, J. Blanco, J. Saiz, Innovación de la gestión técnica de emergencias, *Revista de la SNE*, **166**, 1997.
5. S. Sandra García, Manual del Simulador gráfico interactivo de Zorita (SGIZ), 2009.
6. Simulador Gráfico Interactivo de Zorita. Manual de usuario, Unión Fenosa Generación. Octubre 2006.
7. D. Piedra Prácticas de Seguridad Nuclear, Análisis de accidentes: LOCA, 2009.
8. Principios de operación de la Central Nuclear *José Cabrera* Unión Fenosa Generación. Abril 2008.
9. R. Dávila, Manual de arranque de la central nuclear de *José Cabrera* con el simulador gráfico interactivo de Zorita (SGIZ). 2009.

- Training Programme and Course
- Time required
- Approval List (typically the developer, reviewers, training manager, and operations manager)
- References
- Initial Conditions
- Malfunctions
- Scenario Summary Description
- Training Goals:
  - Generic or general objectives
  - Specific learning objectives

Common Student Errors

- Table with:
  - Evolution or event steps
  - Instructor actions, activities, and information
  - Expected response of each control room position
  - Learning objectives
- SEGs can be classified in three categories:
  - Demonstration scenarios,
  - Training scenarios,
  - Assessment scenarios

The Simulator exercise guides (SEGs) are used in initial training for demonstrating the operation of controls, equipment and systems as well as for training exercises.

The SEGs may be also used as an evaluation tool for individual, as well as team performance.

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