

# Education and Training of Future Nuclear Engineers at DIN: From Advanced Computer Codes to an Interactive Plant Simulator

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## ABSTRACT

This paper summarizes the work being performed at the *Department of Nuclear Engineering* ([www.din.upm.es](http://www.din.upm.es)) of the *Universidad Politécnica de Madrid* to improve the education and training of future Spanish nuclear engineers according to the Bologna rules. We present two main efforts introduced in our programme: i) the understanding of the current computational methodologies/codes starting from the nuclear data processing, then the lattice and core calculations codes, and finally the power plant simulators, ii) the development of practical teaching-learning experiences with an Interactive Graphical Simulator of a real nuclear power plant.

## 1 INTRODUCTION

The present nuclear technology programme implemented in the *Department of Nuclear Engineering* (DIN), named Plan'2000, was approved by the Spanish Ministry of Education, and it has been based on an extended revision of the previous Plan'76 on the nuclear technology programme. In the meantime, the Master/Doctorate in Nuclear Science and Technology belonging to the Official Program of Graduate/PhD is offered by our Department. The main objective of this programme is the training for the development of methodologies of simulation, design and advanced analysis necessary in research and in professional work in the nuclear field, this is, Fission Reactors and Nuclear Fusion, including fuel cycle and safety aspects. The programme includes other basic disciplinary contents such as Quantum Mechanics and Atomic&Nuclear Physics.

In this context, an extensive work was initiated to improve the following subjects in the curricula: “*Nuclear Power Plants (NPP)*”, “*Nuclear Technology*”, “*Nuclear Safety*” and “*Nuclear Reactor Design*”. In this way, the experience gained in the last years by our Department in the development of codes for design and advanced analysis in Reactor Physics has been included in the our programme (e.g. optimization of NPP manoeuvres in PWR). It is summarized in Section 2.

But more realistic studies are also required to complete the education&training objectives in the “*Nuclear Safety*” and “*Nuclear Power Plants*” programmes, and in this sense the use of a simulator is the appropriate tool to be used. The International Atomic Energy Agency (IAEA) sponsors the development of nuclear reactor simulators for education, or arranges the supply of such simulation programs [1,2]. Aware of this, the DIN was provided in 2008 with the Interactive Graphical Simulator (IGS) of the Spanish nuclear power plant José Cabrera, whose operation ceased definitively in 2006 [3]. The simulator is a full scope graphical simulator running in real-time, used during the commercial exploitation of the

plant for training of main control room personnel, technical support engineers, and operations management. In section 3, we present the work performed at the Department to turn the simulator into a teaching/learning tool, to be used in the nuclear engineering studies.

## 2 COMPUTATIONAL CODES FOR NUCLEAR REACTOR DESIGN

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). Some of these codes have been developed in our Department for many years.

Figure 1 shows the different steps of the calculations and their connection of reactor physics design. In addition, we show the associated computational codes introduced in our programme for nuclear reactor designs. The input data for this calculation scheme are the processed cross section libraries and the engineering input data (geometries, composition, power level, operation,...).

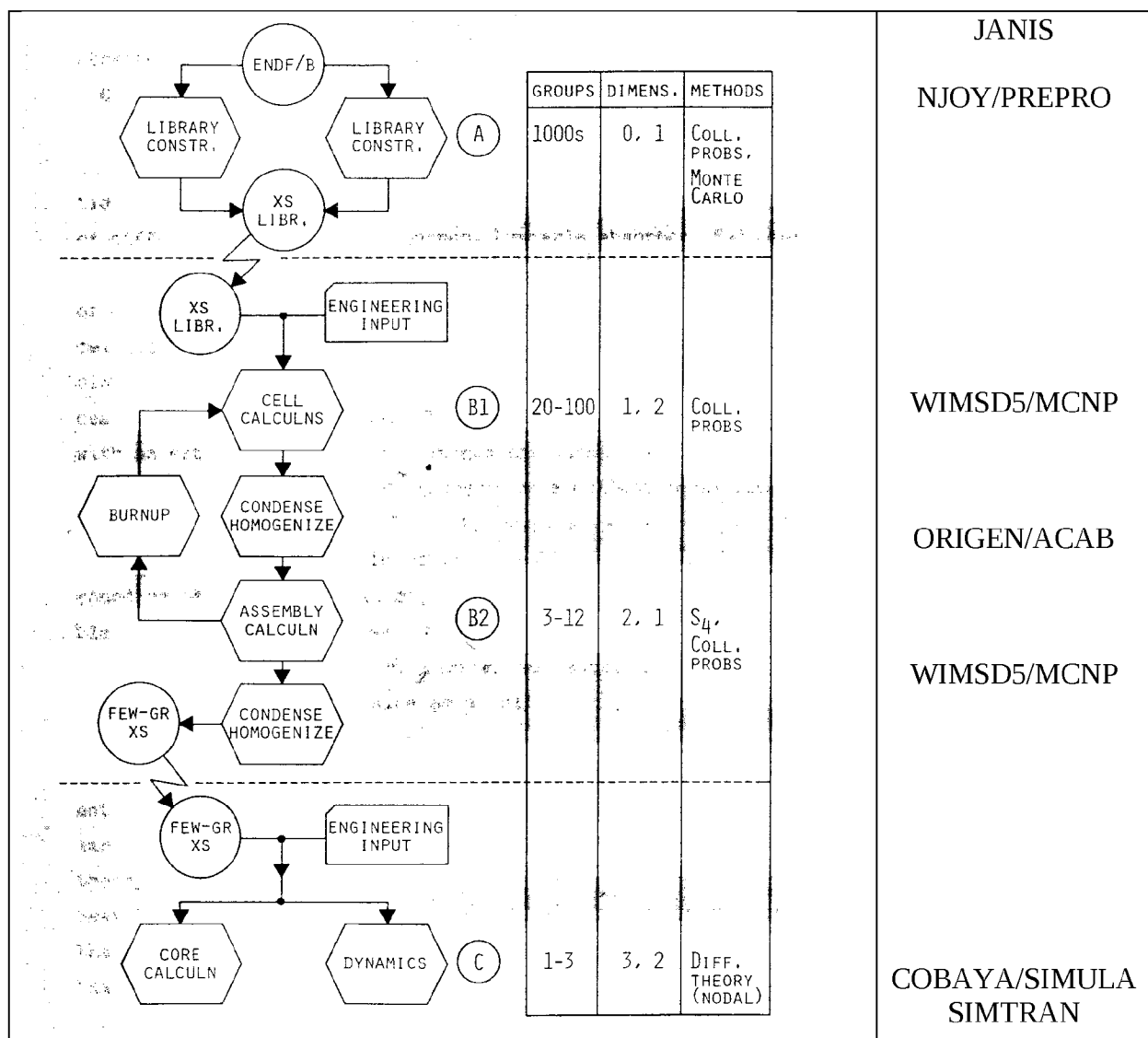


Figure 1: Calculational flow scheme of reactor-physics design [4] and associated computational codes for nuclear reactor designs included in our “*Nuclear Reactor Design*” programme.

We have introduced the generation of cross section libraries for those codes. First, visualizing with JANIS code ([www.nea.fr/janis](http://www.nea.fr/janis)) and checking nuclear data from Evaluated Nuclear Data Files with ENDF Utility Codes ([www-nds.iaea.org](http://www-nds.iaea.org)). Then, processing of nuclear data libraries performed with PREPRO ([www-nds.iaea.org](http://www-nds.iaea.org)) and NJOY, see Figure 2.

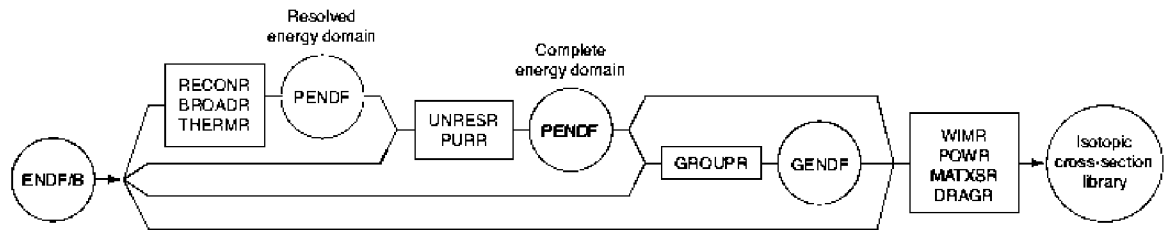


Figure 2: Data flow for multigroup calculations [5]

Different lattice codes have been developed over the years to solve the neutron transport equation in space-energy using microscopic cross-section data. WIMSD4 is used for many years in our Department taking part of the SEANAP system developed by J.M. Aragonés and C. Ahnert for NPP design. Here, WIMSD5 is used to model pin-cells and clusters problems.

Deterministic computational methods are complemented/compared with Monte Carlo calculations. Students are introduced in this methodology and several examples for shielding and criticality systems are simulated with MCNP.

For activation and burn-up calculations ACAB and ORIGEN2.2 codes are used. ACAB code (partially developed in our Department) is designed to perform activation and transmutation calculations for nuclear applications. ACAB has been used to simulate realistic operational scenarios of very different nuclear systems: inertial fusion, magnetic fusion, accelerator driven systems, fission reactors.

Neutronic calculations for core design in 2D and 3D are introduced with COBAYA and SIMULA codes, respectively. These codes also take part of SEANAP system. For core design and operational monitoring we use our SIMTRAN code [6], see Figure 3. SIMTRAN is a 3D-PWR core dynamics code, under development and validation for 20 years. It was developed as a single code merge, with data sharing through the 3D neutron-kinetics nodal code (SIMULA) and the multichannel, with cross flows, thermal-hydraulics code COBRA IIC/MIT2.

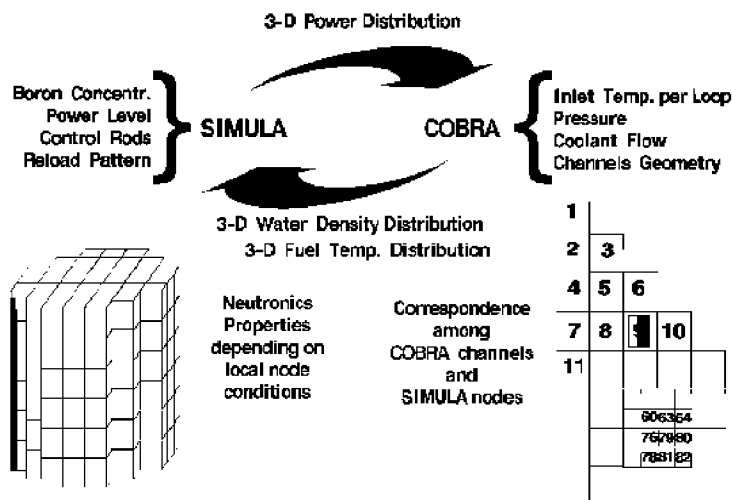


Figure 3: Data flow for the 3D neutronics TH coupling in SIMTRAN

### 3 DESCRIPTION OF THE SIMULATOR

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 [7, 8].

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 to potential equipment problems or unusual conditions.

However, since the simulator has been designed for operator training, multiple activities have been carried out before it was able to be used for effective engineering educational purposes. As an example, taking into account that many operational maneuvers 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 maneuver without running the complete real-time simulation.

#### 3.1 Methodology and main results: Benefits of Simulator use

The simulator installed in the Nuclear Engineering Department includes the hardware and the software that have been used in the José Cabrera NPP for years [8], that is an IGS, which includes the TRAC and RELAP5 codes as the software package, and simulates the PWR physical behaviour under operational and accident situations.

Figure 4 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.* 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 IGS mode.* 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.

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 IGS is the one that has been installed in DIN, see Figure 5, and it is a full scope engineering 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.

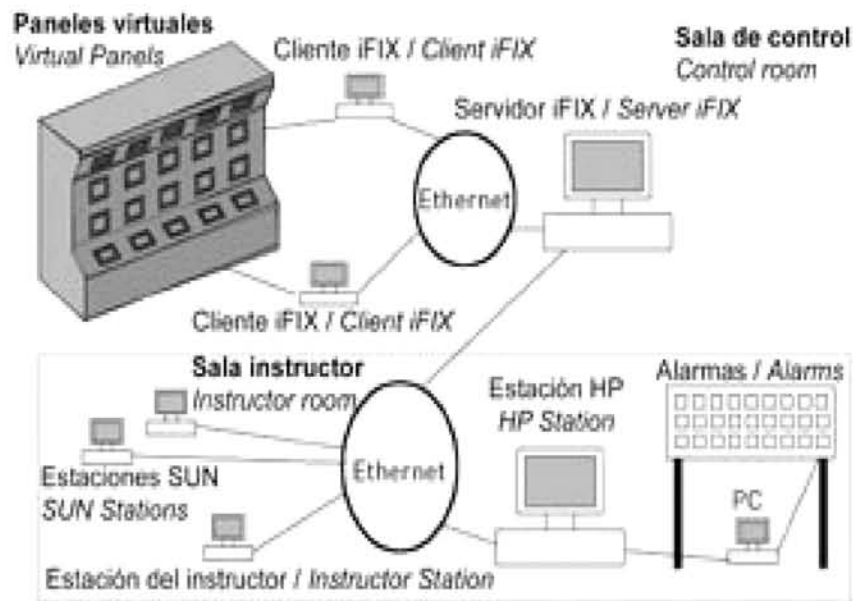


Figure 4: José Cabrera Nuclear power plant General Simulator Arrangement, 1)Control room replica, 2) SGI: Interactive Graphical Simulator



Figure 5: Aula José Cabrera with the Interactive Graphical Simulator (SGI)

In Figure 6, the components and systems of the whole power plant are simulated in the Simulator, this includes the nuclear reactor, the pressurized vessel, the primary and secondary loops, the turbine, the condenser, 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 provide 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 identified 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 clicking in a component and getting the information in a graphical way. The components are represented in different screens with diagrams where the different colors indicates the status of the component (open/close, on/off,...)

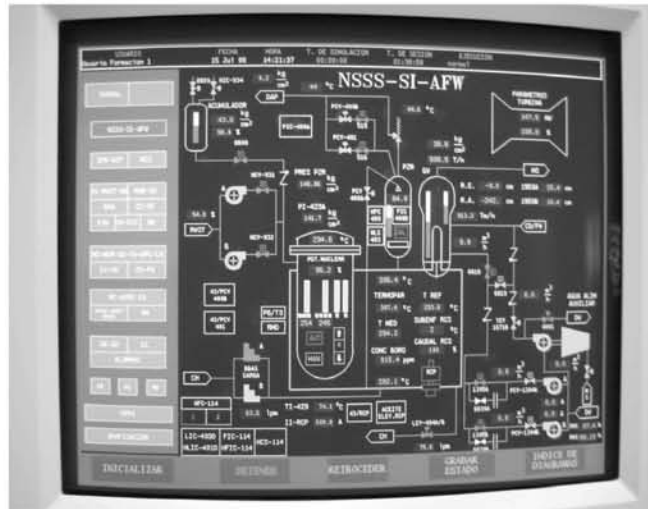


Figure 6: One Screen with reactor vessel, injection system, and auxiliary feedwater system

The simulator provides the real plant responses (see Figure 7) during the normal operation, and simulates several maneuvers, a series of malfunctions, and operational transients, and it also allows the training in the emergency procedures. With the simulation of these situations the student is trained in the plant behavior, and in the nuclear and thermohydraulic phenomenology in the nuclear reactor and in the components of the whole plant.

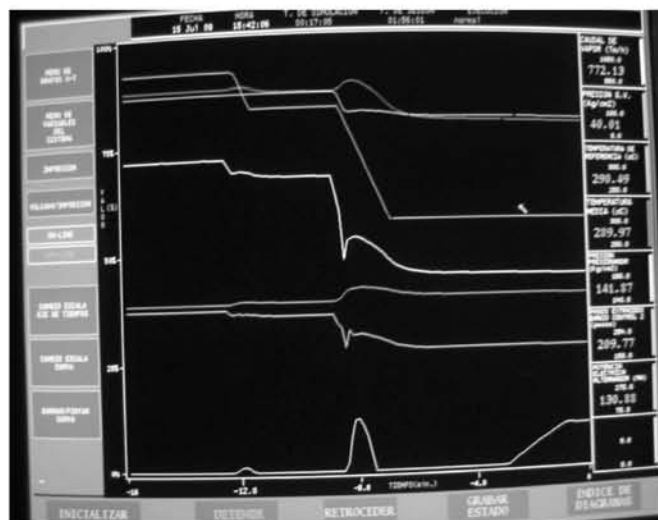


Figure 7: One scheme with graphics provided by the Simulator

As an example of standard operational situations that we have 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

Also, IGS allows the simulation in hypothetical accidents, those which are complex and with a very low probability to happen. This is use in the training, in order to understand the

optimal way to drive the plant to a stable and safe situation. For the simulation of the accidents, the best-estimate and realistic codes are used. The evolution is done in real time, and the student because of that 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: Loss of coolant accident (LOCA), Steam generator leak, main pump rotor stopped, transients with the protection system failure and the reactor scram, etc...provides the student the detailed understanding of the heat transmission and fluids mechanics, the kinetic reactor behavior and the coupling among them. These more complex situations are for the moment under testing, because this should be done when the more simplex transients and maneuvers are completely known by the student.

As a sample the students have the following documentation available for the Nuclear Safety practices: Practice Manual (description of the practice, systems involved (see Figure 8), 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).

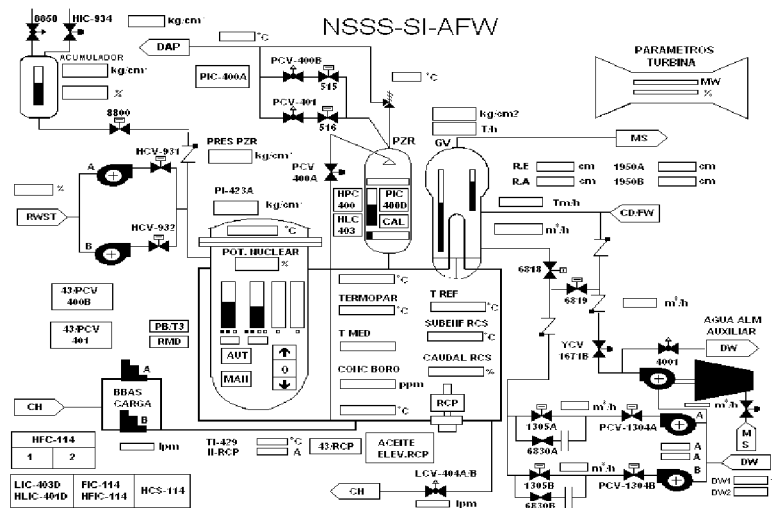


Figure 8: One scheme provided to the students with the systems diagram

#### 4 CONCLUSIONS

The introduction of the current computational methodologies/codes for reactor nuclear designs in our programme has covered a difficult gap between nuclear reactor theory and simulations. For students, the understanding in a comprehensive way of these codes is an important value in simulation, design and advanced analysis both in the research activities and in the professional work.

The IGS has been shown like 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. Also has been shown as a relevant tool for motivation of the students, and to complete the theoretical lessons. Also follows the tendency recommended for the Bologna adapted studies, as 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.

## ACKNOWLEDGMENTS

We would like to dedicate this article to our friend and colleague, Jose M. Aragonés, who passed away on the 27th of July 2010. Professor Aragonés was Chair of Nuclear Physics and Head of Reactor Physics Division at the Instituto de Fusion Nuclear.

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