

**Full Scope Simulators (FSS) have long been an indispensable part of the licensed training program for nuclear power plant control room operators. Traditionally relatively complex and time-consuming to create and validate, and inextricably linked to the design and operational data of the reference plant that they reproduce, simulators have typically been planned as a single deliverable occurring relatively late in the plant design process. As a complete, integrated dynamic representation of the behaviour of a plant’s process and control systems in their various states of operation, upstream simulation’s value is gradually being recognized for non-traditional applications such as initial learning, procedure development and verification, design verification and Human Factors Engineering. Nevertheless, the structured integration of simulation into the planning of the power plant design and training cycle has been somewhat slow. This paper looks at the opportunities for simulation in the entire plant life cycle and includes examples of experience from recent L3 MAPPS projects in which simulation has played a wider role.**

## Introduction

Nuclear power plant simulation has traditionally focused on plant-specific Full Scope Simulators (FSS) with the primary objective being licensed operator training. The initial development and delivery of the vast majority of the FSSs have taken place either late in the plant construction cycle or following commercial operation. The development of an FSS has typically taken two to three years with a single integral delivery at the end of the project. The availability—or for that matter the need—for any kind of staged or incremental delivery of the evolving simulation or its use outside of operator training has been very limited.

The confluence of Nuclear New Build (NNB), widespread use of digital control systems (DCSs), powerful model development and training delivery tools and extremely inexpensive computation is leading to a paradigm shift in how and when simulations are created and used. In particular, the convergence of “simulation engineering”—the development and validation of an FSS by a simulator vendor—and “engineering by simulation” towards leveraging the investment in model development has the potential of detecting latent design defects and thus reducing risk and optimizing plant design and cost.

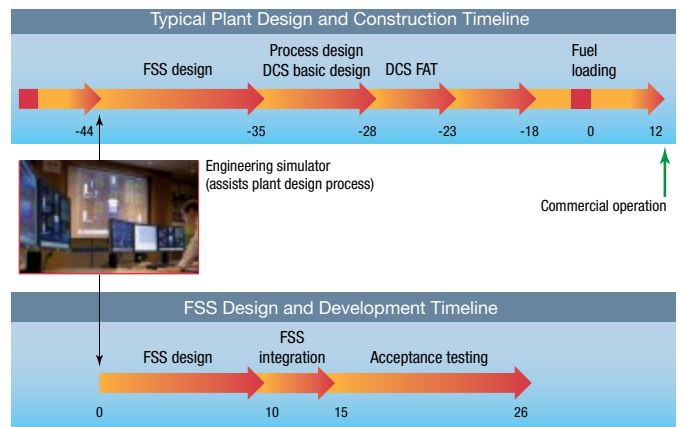
## Nuclear New Build

The primary requirement for FSS for NNB is that training starts 12 to 24 months before fuel loading. This provides both a challenge and an opportunity for the FSS.

Figure 1 shows the schedule for the development cycle of a typical nuclear power plant and its associated FSS. The development of the FSS is inextricably linked to the design and operational data of the reference plant that it reproduces. Simulation of the plant process begins as much as 44 months before fuel loading. The primary challenge is related to the fact that the simulator development, and in particular integration and validation, takes place in parallel to the basic and detailed design of the DCS and well ahead of plant commissioning. Periodic updates following the actual plant commissioning and commercial operation typically take place 12 to 24 months after initial delivery.

There are consequences to this parallel development. These consequences include the fact that the plant detailed design is incomplete, that limited DCS verification and validation (V&V) has taken place at the time of FSS integration and that the turnaround time to solve plant design issues discovered during simulator testing can be long, as it is driven by the plant schedule and the DCS supplier’s quality process. The concept of a data freeze does not apply—change is inevitable during the FSS project and must be managed by the simulator developer. Above all, the simulator becomes a de facto V&V tool for plant design verification and virtual commissioning.

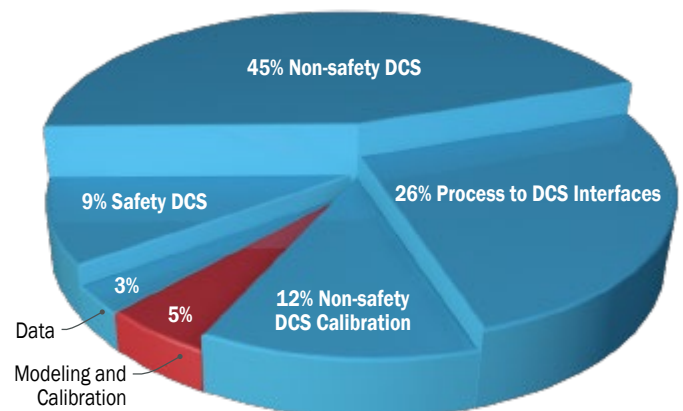
The opportunity is that this virtual commissioning through simulation can be a valuable tool for detecting and correcting latent errors that would otherwise need to be addressed during the actual commissioning of the plant (or later).



**Figure 1: Plant and simulator development**

L3 MAPPS’ experience with several new build programs (e.g. Olkiluoto 3 (OL3) (Finland), Ling Ao Phase II (China), Hongyanhe Phase I (China)) has shown that a large number of plant issues will in fact be detected during simulator testing. Typical issues include programming errors that are introduced during either the basic or detailed DCS design phases, inconsistent signal interfaces between different DCS products and between the control system and plant components, and inadequate parameterization at the time of simulator testing.

Figure 2 shows an example of the distribution of simulator discrepancies detected and resolved during testing of an L3 MAPPS FSS for a NNB. As can be seen, the vast majority of discrepancies are related to plant (rather than simulation) issues that would otherwise be detected only during actual plant commissioning and operation.



**Figure 2: Distribution of Discrepancies Found During FSS Testing**

Nevertheless, the effort required to discover, correct and validate the plant design changes by the plant or DCS vendor can have a harmful impact on the FSS schedule and the power plant owner’s licensed operator training program. The way to mitigate this effect is to include the virtual commissioning in the overall planning and development cycle of the plant. This requires that the simulator be considered within the big picture of the plant construction schedule. If this is not done, the FSS development schedule and training will be compromised and the plant commissioning schedule will be put at risk.

## Engineering Simulation

Virtual commissioning is one example of the use of an Engineering Simulation (ES). One of the important criteria is the use of the same detailed, high-fidelity models of the plant systems that will eventually be developed for the FSS. Unlike the Nuclear Plant Analyzers of the 1990s which focused on primarily NSSS modeling and transient analysis, the ES relies on a plant model that is a complete, integrated, dynamic representation of the behaviour of all the plant systems controlled by the DCS (or DCSs) in their various states of operation. In fact, the primary difference between an ES and an FSS is simply a reduced hardware footprint and the absence of a need to fully reproduce the control room environment.

A second important criterion is related to the DCS itself. For the purposes of V&V, the implementation of the DCS in the simulator should ideally be based on running the same DCS application software that runs on the actual plant controllers. This requires a binary equivalent machine emulation (or virtual stimulation) from the DCS vendor (see [www.mapps.l3t.com/simulator-distributed-control-systems.html](http://www.mapps.l3t.com/simulator-distributed-control-systems.html) for a definition of DCS simulation techniques).

The use of a complete plant model allows a level of V&V that is not possible on a typical DCS test facility. It also allows the use of the ES for plant procedure development and validation. L3 MAPPS has delivered the OL3 ES that is used for V&V testing and procedure development and validation.

Although the integrated ES described above has obvious advantages for V&V testing, there are two important disadvantages. The first is that the ES is available relatively late in the plant construction. This is partially because it has been derived from the FSS development and above all because the V&V testing can only begin once the detailed design of the DCS is complete and the DCS application software is available. The second is that there has been no prior, simulation-based opportunity to minimize discrepancies at either the system or basic design level before preparation of the DCS application software.

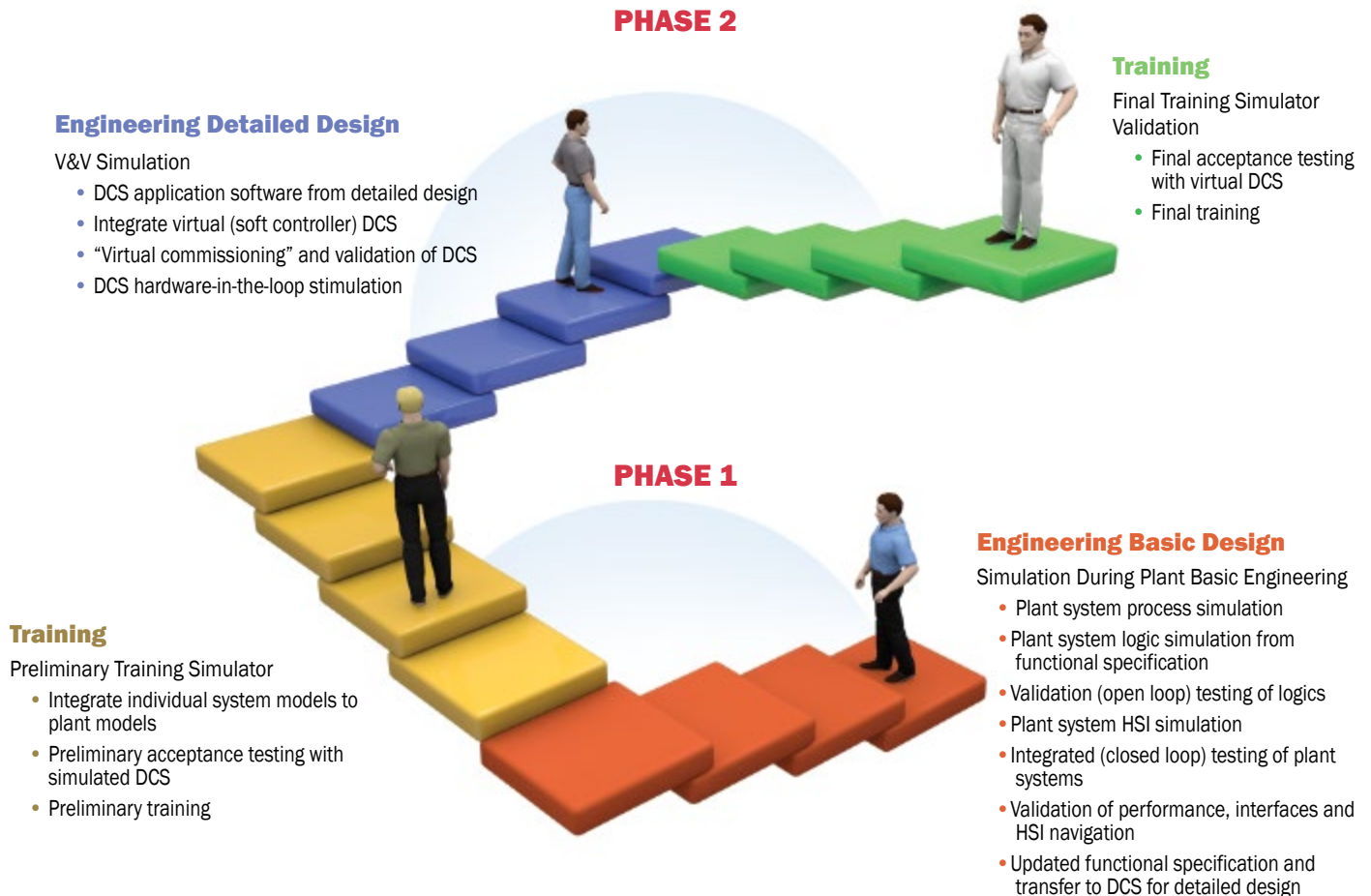


Figure 3: Two-phase approach

The solution is to perform incremental simulation-based testing on a system level in parallel to plant system design. See Figure 3. This upstream integration of the ES into the plant design process makes it possible for simulation to achieve its full potential.

Though the benefits seem obvious, the industry has truly embraced the technology only in recent years. One reason is that simulators have traditionally been viewed as training devices with computational limitations. This is no longer the case. Another reason may be the perception that the data required for simulation will not be available soon enough to support early development of the individual simulations. In fact, the data that is required to start simulation of a particular system is the same data that is required to start the basic I&C design for the system. This essentially consists of the general system performance and safety requirements and P&IDs. This information is generally found in the preliminary system design manuals. Generic component data can be used until such time as vendor data is available from the detailed design.

This strategy of continuous evolution of the simulation (from system level to plant model to V&V simulator to FSS and data-driven updates from basic design to equipment specification to DCS application software) requires state-of-the-art configuration control mechanisms for the simulation toolset in order to ensure an efficient workflow. L3 MAPPS' Orchid® simulation tools, and in particular the Orchid® Modeling Environment (Orchid® ME), are specifically designed to ensure configuration control. Orchid® ME is a client-server application designed to support large development workgroups working in a constantly changing environment. Orchid® ME includes many features that are unique among model builders including individual and shared workspaces, a check-in/check-out mechanism, versioning control over simulation schematics and component libraries, integrated source data referencing and validation, visual comparison tools for all sources including simulation schematics, support for geographically distributed workgroups and automated testing, data gathering and regression analysis features.

## SOFIA

SOFIA (*Simulateur d'Observation du Fonctionnement Incidentel et Accidentel*) is an example of another ES with a different set of goals. SOFIA has been developed jointly by L3 MAPPS, AREVA and the *Institut de Radioprotection et de Sûreté Nucléaire* (IRSN). SOFIA includes separate simulations of four different types of French nuclear power plants including a Generation III+ EPR™. The SOFIA ES at IRSN is shown in Figure 4.

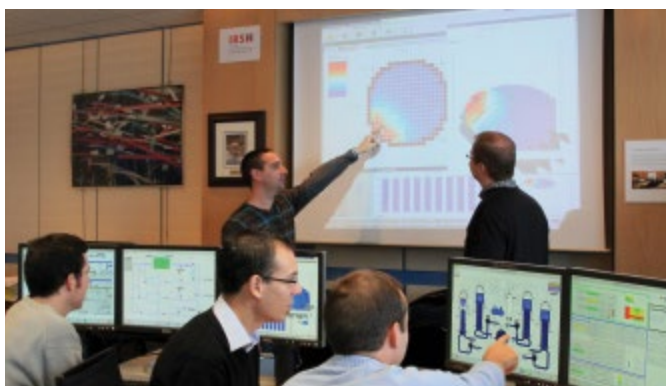


Figure 4: SOFIA at IRSN

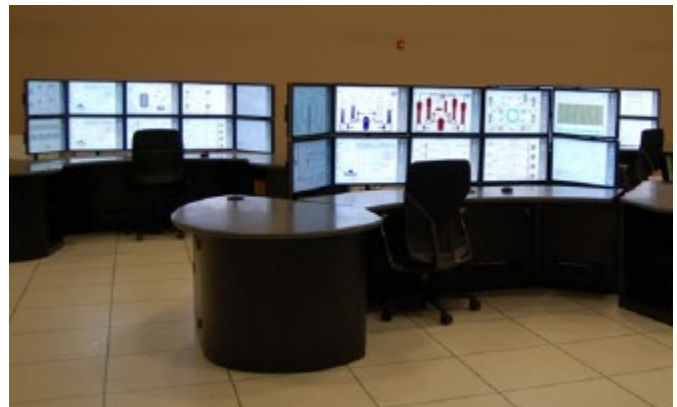


Figure 5: CAER's Reconfigurable Main Control Room Simulator

The simulators run within the Orchid® simulation environment, and most of the models have been developed with Orchid® ME. Each simulation includes a plant model that supports a scope of simulated operations equivalent to an FSS. All the simulators include the CATHARE 2 code for modeling of the NSSS. CATHARE 2 is a system code for PWR safety analysis, accident management, definition of plant operating procedures and for research and development. It is also used to quantify conservative analysis margins and for licensing. The EPR version also includes simulation of the core neutronics with Orchid® Core Builder. Unlike an FSS, SOFIA does not reproduce a specific control room environment but rather uses a DCS-like HMI interface that allows the user to carry out all procedures available to operators.

SOFIA serves both training and engineering functions. As a training simulator, it is used to provide training in elementary plant systems and operating strategies during incident and accident situations to design and commissioning engineers, nuclear safety authority inspectors and IRSN safety specialists. As an ES, it is used to perform studies related to complex accident sequences that require an overall plant model, to design and validate procedures, to support the safety analysis of planned plant modifications and to develop emergency procedures and drills.

A key technology difference between the OL3 ES and SOFIA is the use of a simulated version (instead of an emulated version) of the DCS. This difference reflects the different objectives of the two simulators. The objective of the OL3 ES is the V&V of the actual DCS application software destined for the plant. One of the goals of SOFIA is validation of system design modifications at the basic design level, particularly in terms of control strategies, operating procedures analysis and improvement, preliminary safety analysis and plant engineering and emergency response training. In this case, a key requirement is the ability to rapidly develop and test alternate control strategies using Orchid® development tools and support for multiple software configurations.

## Human Factors Engineering

Another example of where upstream simulation is playing a vital role is in Human Factors Engineering (HFE). The Center for Advanced Engineering Research (CAER) has set up a research facility that includes a Reconfigurable Main Control Room Simulator (RMCRS). It is specifically designed to support research into Generation III/III+ control room design, human factors studies for new power plants and digital I&C.



In this case a specific plant-referenced simulation is less important than a simulation that supports the full operating envelope including major transients that an operator may see. L3 MAPPS has provided an EPR plant model with typical HMI displays that are used as the operator interface and the software tools that allow the user to modify or test new displays. The RMCRS is shown in Figure 5. The simulator includes sophisticated eye-tracking technology and event-logging software for the collection and analysis of human performance data.

CAER's plan includes the study of the impact of I&C system failures on operator performance by interfacing an actual AREVA TELEPERM XS digital safety system to the plant model.

Similarly, Idaho National Laboratory (INL) is using simulators as part of the Human Systems Simulation Laboratory (HSSL) to develop and test newer digital control room designs, especially in terms of digital control room upgrades of existing plants. INL is currently conducting research to support the upgrade of the main control room at the San Onofre Nuclear Generating Station (SONGS), a two-reactor plant operated by Southern California Edison Company. The existing SONGS simulator software, already using L3 MAPPS' platform and models, is complemented by L3 MAPPS' Orchid® Touch Interface using touch-screen technology to provide a virtual representation of the control room hard panels. The software development tools will enable INL to create and study different panel prototypes. The prototypes will be evaluated using operator-in-the-loop testing, and basic operator performance principles will be disseminated to the industry. Utilities will then work with their plant vendors to apply research-derived principles as design recommendations for their specific needs.

## New Training Applications

Licensed operator training has traditionally used a combination of classroom fundamentals and procedure-driven, FSS-based operations training. However, the industry is facing the challenge of training an emerging, new generation nuclear workforce. Simulation can also be used upstream of operations training to facilitate understanding of the physical process and interactions that take place during power

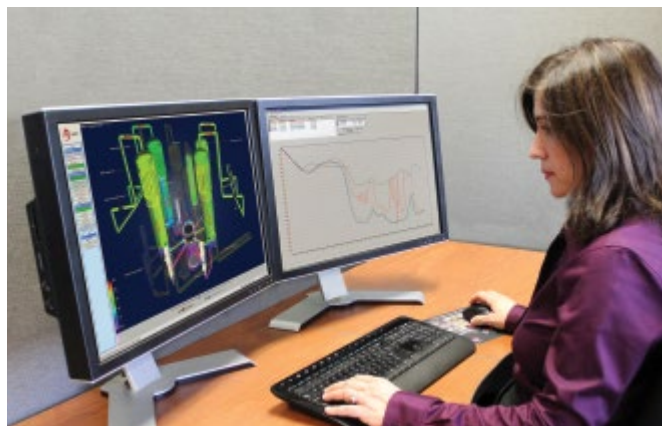


Figure 6: 3-D Transient Fundamentals Trainer

plant operation and transients. L3 MAPPS is coupling 2-D and 3-D visualization technology and simulation to bring real-time, simulation-driven, animated physical systems allowing immersive, participatory learning in the classroom. The visualization can either be coupled to generic power plant simulation that provides fundamental training or to an FSS. See Figure 6.

## Conclusions

FSSs have traditionally been used to deliver operations training. However, the accuracy and depth of today's models and the plant data that they encompass provide opportunities for leveraging the investment in the models for their use in engineering. The structured integration of simulation into the plant engineering process is a means of reducing cost and risk by integrating simulation-based V&V early in the development cycle. An efficient workflow requires simulation tools with state-of-the-art workgroup and configuration control features. Simulation is also a means of providing fundamental learning to the new generation nuclear workforce through hands-on, immersive visualization and learning.

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