RECENT ADVANCES IN NUCLEAR POWER PLANT SIMULATION

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Abstract

The field of industrial simulation has experienced very significant progress in recent years, and power plant simulation in particular has been an extremely active area. Improvements may be recorded in practically all simulator subsystems. In Europe, the construction of new full- or optimized-scope nuclear power plant simulators during the middle 1990's has been remarkably intense. In fact, it is possible to identify a distinct simulator generation, which constitutes a new de facto simulation standard. Thomson Training & Simulation has taken part in these developments by designing, building, and validating several of these new simulators for Dutch, German, and French nuclear power plants. Their characteristics are discussed in this paper. The following main trends may be identified :

- Process modeling is clearly evolving towards obtaining engineering-grade performance, even under the added constraints of real-time operation and a very wide range of operating conditions to be covered.
- Massive use of modern graphic user interfaces (GUI) ensures an unprecedented flexibility and user-friendliness for the Instructor Station.
- The massive use of GUIs also allows the development of Trainee Stations (TS), which significantly enhance the in-depth training value of the simulators.
- The development of powerful Software Development Environments (SDE) enables the simulator maintenance teams to keep abreast of modifications carried out in the reference plants.
- Finally, simulator maintenance and its compliance with simulator fidelity requirements are greatly enhanced by integrated Configuration Management Systems (CMS).

In conclusion, the power plant simulation field has attained a strong level of maturity, which benefits its approximately forty years of service to the power generation industry.

1. INTRODUCTION

The field of industrial simulation has experienced very significant progress in recent years, and power plant simulation in particular has been an extremely active area. Improvements may be recorded in practically all simulator subsystems. The impressive increase in computer power at affordable prices which has taken place uninterruptedly in the last decade has strongly supported this evolution.

In Europe, the construction of new full- or optimized-scope nuclear power plant simulators during the middle 1990's has been remarkably intense. It is in fact possible to identify a distinct simulator generation, which constitutes a new de facto simulation standard. Thomson Training & Simulation has taken part in these developments by designing, building, and validating several new simulators for Dutch, German, and French nuclear power plants. This paper is based on an analysis of the characteristics common to the following simulators :

Reference Power Plant	Country	Type and Rating (MWe)	Vendor
Unterweser	Germany	PWR - 1350	Siemens
Neckarwestheim	Germany	PWR - 840	Siemens
Borssele	Netherlands	PWR - 480	Siemens
Obrigheim	Germany	PWR - 350	Siemens
Fessenheim-1	France	PWR - 900	Framatome
Bugey-2	France	PWR - 900	Framatome
N4 (Chooz)	France	PWR - 1500	Framatome

2. MAIN NEW TRENDS

As mentioned above, practically all the subsystems which are integrated in a simulator have been subjected to drastic improvements. The more salient features are :

- Process Modeling is clearly evolving towards obtaining engineering-grade performance, even under the added constraints of real-time operation and a very wide range of operating conditions to be covered.
- The *Instructor Station (IS)* has been improved beyond recognition by the massive use of modern graphic user interfaces (GUI), which ensure unprecedented flexibility and user-friendliness.
- New *Trainee Stations (TS)* have been developed, again based upon the massive use of GUIs. They significantly enhance the in-depth training value of the simulators.
- *Software Development Environments (SDE)* have become remarkably powerful. They enable the simulator maintenance teams to keep abreast of modifications carried out in the reference plants.
- Finally, integrated *Configuration Management Systems (CMS)* enhance simulator maintenance and its compliance with simulator fidelity requirements.

Let us now take a detailed look at each of these advances.

3. PROCESS MODELING

The main purpose of the simulators listed in § 1 is the training of plant personnel. Their modeling capabilities, however, go far beyond the actual training needs. In fact, their modeling level is such as to make them ideal development tools. The following engineering applications have already been performed in some cases :

- studies of control room ergonomy.
- development and testing of new operating procedures.
- impact studies of proposed plant modifications.

In fact, process modeling for training simulators is rejoining the mainstream of engineering calculations [1-2], and training simulation models can no longer be dismissed as clever artifices. They are getting ever more powerful and accurate, while still retaining their usual advantages over engineering models, namely real time performance and a very large scope of simulation, as they must cover plant operation from cold shutdown to full power, plus malfunctions and operator errors and/or omissions.

The main modeling improvements which can be observed in the new simulator generation are :

- the implementation of CATHARE-SIMU, the real time version of the French best-estimate thermohydraulic code CATHARE. This code covers the simulation of the reactor coolant system, the steam generators, and the steam lines.

  CATHARE is a two-fluid, 6-equation, best-estimate thermohydraulic code, developed by EDF, the French national utility, and the French Commissariat à l'Energie Atomique (CEA). Its real time version was developed by CEA and EDF in partnership with TT&S. CATHARE has been validated against a large number of separate-effects and global experiments, and is the thermohydraulic code officially used in France for carrying out design and safety studies. This level of modeling of course ensures the physical adequacy of simulator response under the most complex normal and off-normal operating conditions.

- the implementation of LIBELLULE, a fuel management code developed by EDF, for the simulation of the core physics. Besides enhancing the modeling performance of the simulator, this development ensures the ready maintainability of the simulator with respect to future core loading changes.

  As implemented in the simulators, LIBELLULE calculates the core cross sections as a function of operating conditions and solves the complete neutron diffusion equations for two neutron energy groups. The number of axial layers in the actual applications is between 45 and 60.

- the development and implementation of a 3D core model capable of reproducing the calculations of the German fuel management codes MEDIUM-2 (Siemens) and RSYST3 (IKE-Stuttgart) with good accuracy.

  This model is based on the complete 3D neutron diffusion equations for two energy groups. The axial mesh is identical to that of the reference codes, and the radial calculations use one mesh point per fuel assembly (with four flux values per mesh point).

  The core cross sections are determined by fitting polynomials to the data points supplied by the reference codes, using the least-squares method.

- the generalized use of code generators for the modeling of conventional plant systems :
  - VAPNET, for all two-phase steam/water networks in the secondary system, including turbine, condenser, reheaters, etc.
  - HYTHERNET, for homogeneous flow in fluid networks (steam/water, oil, air).
  - CONTRONET, for the simulation of logic and analog instrumentation and control systems.
  - DELNET, for the simulation of electrical distribution systems.

4. INSTRUCTOR STATION

As indicated above, the Instructor Stations (IS) have been modified beyond recognition by the massive application of graphical user interfaces (GUI). The capabilities of modern IS extend well beyond the traditional management of training sessions. The IS provides much more than the classic functions such as freeze/run, backtrack, snapshot, etc.

In fact, the IS has become a full-fledged tool for training management. It relieves the Instructor from tedious routine work in several areas :

- **Training session preparation.**
  - the selection of appropriate initial conditions has been simplified by the use of selection criteria, such as fuel cycle and power level.
  - the control room check is performed automatically.
  - the creation of training scenarios is now much more powerful. Malfunction sequences may be defined by the chaining of logic conditions, which depend on elapsed time and/or the value of any simulated variables. The use of generic malfunctions, and the possibility of overriding any control room input make the number of possible scenarios virtually unbounded.

- Training session management.

The new IS allows the Instructor to follow the exact sequence of events taking place in the control room from the IS, well away from the trainees. This is made possible by the advanced GUIs at his/her disposal :

- *interactive photopanels (soft panels).* These screen displays are exact reproductions of the control room panels. The photopanels are fully interactive, as everything is reproduced: indicator needles move, alarms flash as appropriate, etc. The Instructor may even introduce spurious operator actions, not only by overriding the control room inputs, but also directly, clicking on pushbuttons, turning selector switches, etc.
- *interactive plant diagrams.* These displays are exact reproductions of the plant system Piping & Instrumentation Diagrams (P&Ids). They display the actual value of all required process variables, and they also allow the Instructor to activate malfunctions and to control plant equipment.
- *operator logbook.* This function provides the Instructor with an instantaneous record of the trainee's actions. Errors may then be corrected immediately if so desired, or the entire sequence may be stored for later review and evaluation.

- *graphical variable displays.* Process variables may be displayed graphically during simulation. The Instructor can easily create any number of variable groups as necessary to follow the different training scenarios. Variables may be readily added or suppressed during actual real time simulation.

5. TRAINEE STATION

There is no point in restricting the great possibilities offered by advanced GUIs to the traditional Instructor Stations. It has been standard practice to organize plant operator training on simulators in two more or less separate stages :

- "understanding", "in-depth", or "physical insight" training.
- "operational" or "reflex" training.

Traditionally, different simulators were used for each training stage, namely a "basic principles" simulator for physical insight, and a full- or optimized-scope simulator for the reflex training. It was thought that full-scope simulators were so complex that they could not possibly allow "understanding" training at all.

It is our contention that this traditional view does not hold anymore, precisely because of the tremendous progress which has been accomplished in the graphical representation and condensation of data. The continuous advances in graphic display techniques will thus allow the Trainee Station (TS), coupled to a full-scope simulator, to be used also for "in-depth" training of plant operators or safety supervisors.

All the graphical resources implemented in the Instructor Station may be made available for the trainees. They can thus follow the evolution of process variables in detail, and relate them to their actions and the actions of the different control and protection systems.

Furthermore, a second simulation load may be run on spare cycle time, even in parallel with the main simulator. The TS will thus allow for instance experienced operators to review scenarios and operating procedures on a more flexible schedule, without requiring permanent Instructor assistance.

The future is prefigured by the ACTIV training tool, which allows the graphical representation of the thermohydraulic and chemical conditions in the plant systems [2-3]. ACTIV shows graphically ("echographically") the actual flow regime conditions in the reactor coolant system and the steam generators. The trainee really sees steam, water, or steam/water mixtures flow in the pipes, level drops in case of LOCA, etc.

ACTIV is not a cinema gimmick: the spatial mesh of the graphical representation is exactly the same as the one used in the thermohydraulic model, and the graphical representation at each mesh cell depends directly on the values of the thermohydraulic variables at that cell.

The trainees using ACTIV gain a much deeper "feeling" of how their actions translate into flow conditions, why these actions are required, and so on. The direct visual observation of the physical phenomena underlying plant behavior makes then a more lasting impression, and real understanding is much easier to achieve.

6. SOFTWARE DEVELOPMENT ENVIRONMENT

The Software Development Environment (SDE) has been developed by TT&S as an integrated set of software tools geared towards the development, testing, integration, and maintenance of simulation software, i.e.:

- non-modeling software, via a generic software environment for software production, testing, integration, and management, called *ATGL*.
- modeling software, via *SWORD*, a dedicated software environment.
- documentation, via the Configuration Management System, *CMS*.

The overall structure of the SDE is shown in Figure 1.

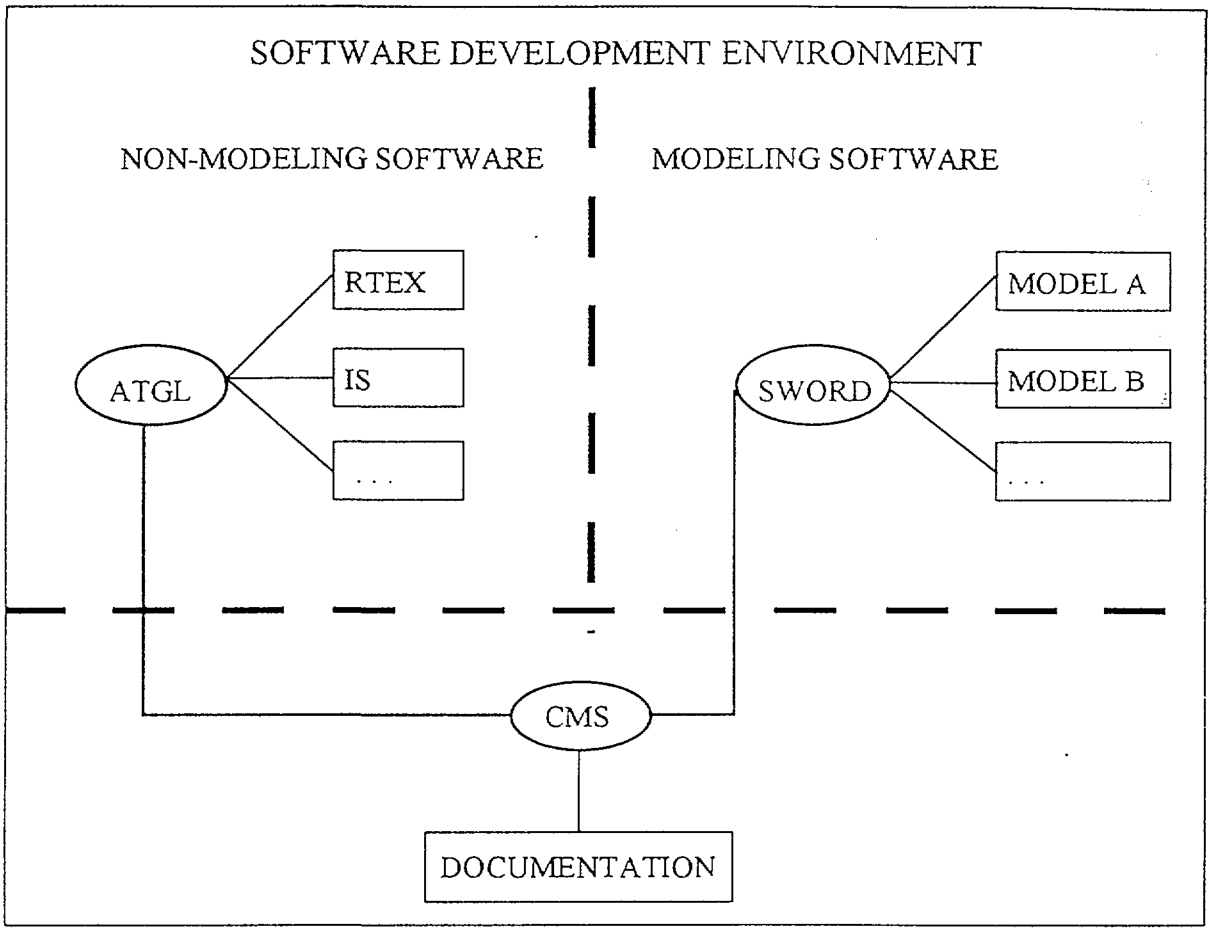


Figure 1 - Overall SDE structure

ATGL is not specifically oriented towards simulation, and we shall not describe it here in detail. It is used for the development and management of the following software components of the simulator :

- *RTEX*, the real time executive.
- *IS*, the Instructor Station software.
- *TS*, the Trainee Station software.
- the software tools which compose the SDE environment (SWORD, CMS) itself.

6.1 MODELING SOFTWARE ENVIRONMENT, SWORD

6.1.1 SWORD Functional Structure

The **SWORD** environment has been described in detail in reference [4]. It possesses an integrated set of software tools :

- **ADMIN,** an administration system which provides the primary access to SWORD, and ensures the overall consistency of the production process for modeling software.
- a set of modeling code generators :
  - **VAPNET**, for the simulation of steam/water circuits,
  - **HYTHERNET**, for the simulation of hydraulic circuits,
  - **CONTRONET,** for the simulation of logic and analog control systems,
  - **DELNET**, for the simulation of electrical systems.
- **CNX,** a set of assembly tools for automatically connecting the model interfaces and creating an integrated total or partial simulation load.
- **PANEL,** a utility for real-time, on screen display of interactive detailed process and instrumentation diagrams of the plant systems.
- **TEST,** a utility for real-time, on-screen graphical display of the time evolution of simulated variables.

6.1.2 SWORD Development Process

An overview of the software development process followed under SWORD is represented in Figure 3.

Two development «spaces» are recognised by SWORD :

- a "working" (or production) space, where software items are first produced, and then tested and validated.
- an "official" space, where validated items can be imported from the working space. Software items in the official space may of course be recovered for subsequent use in the working space.

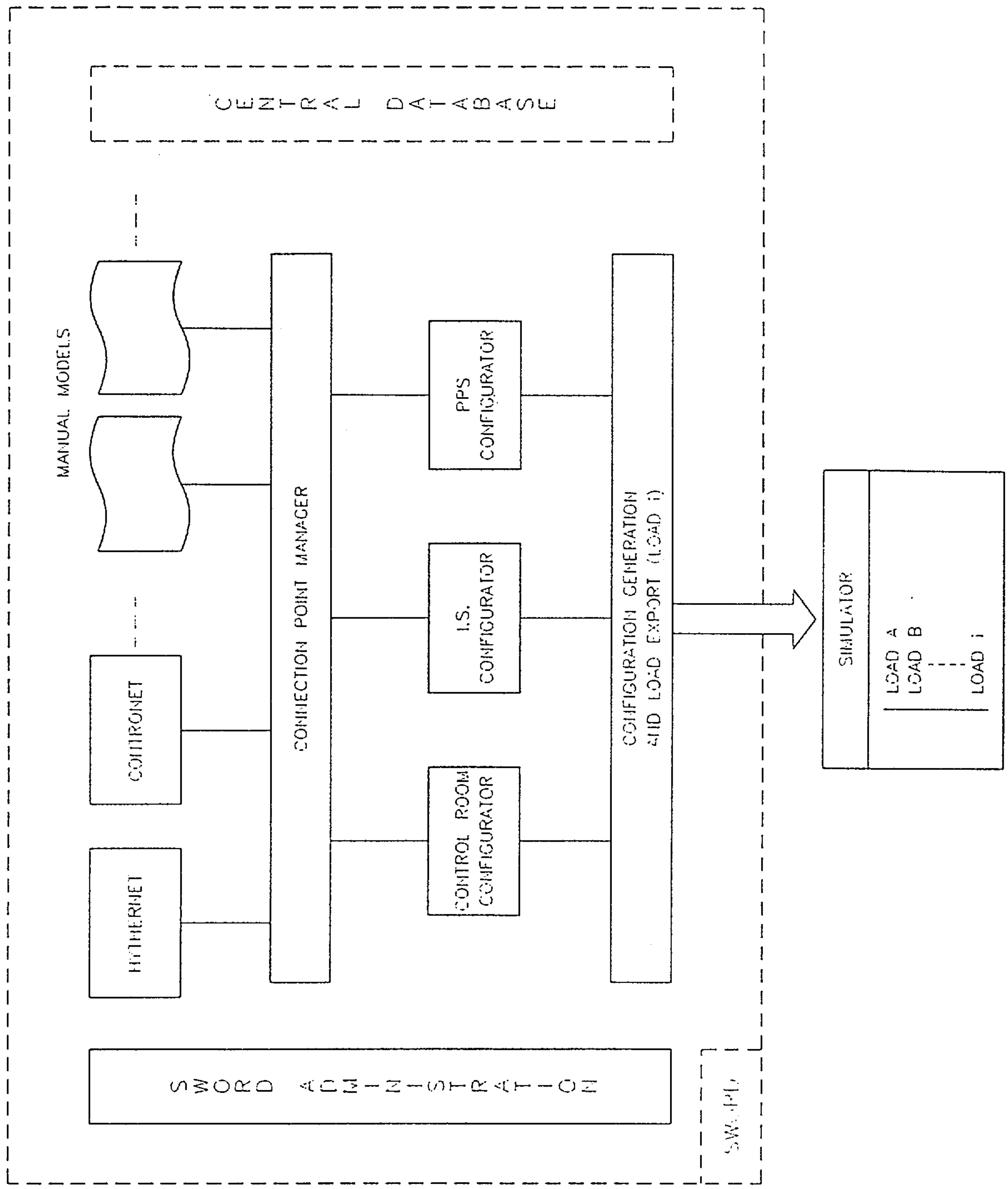


Figure 2 - Overview of SWORD development environment

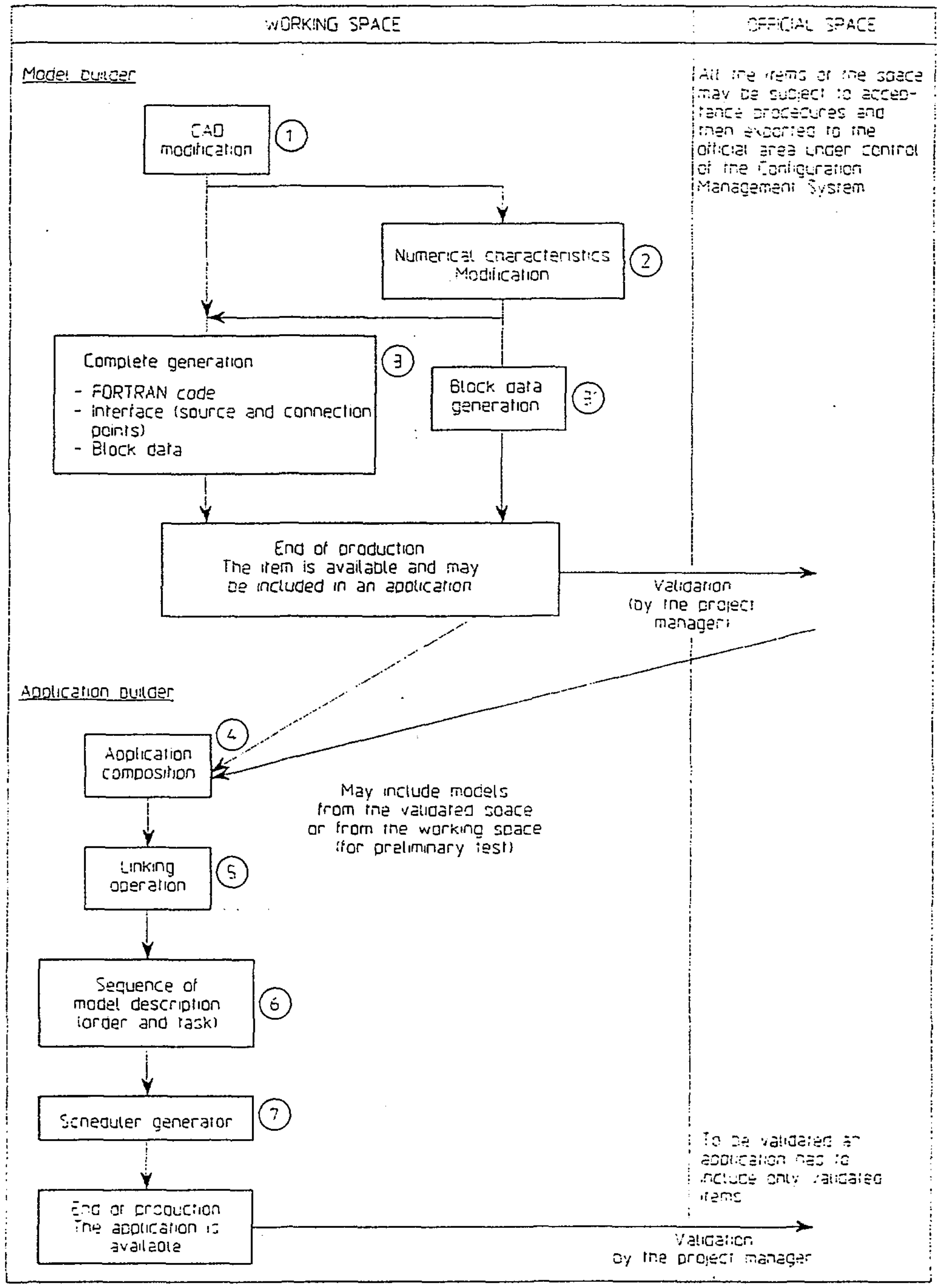


Figure 3 - Chain of production of modeling software

6.2 CONFIGURATION MANAGEMENT SYSTEM

The Configuration Management System manages the overall software process and its documentation during the different phases of software development. Its main functions are as follows:

- management of the scope of simulation,
- management of software modifications,
- identification of software versions,
- production of documentation.

Theses functions enable to CMS fulfill the requirements set off by the ANSI/ANS-3.5-1993 standard in regard of :

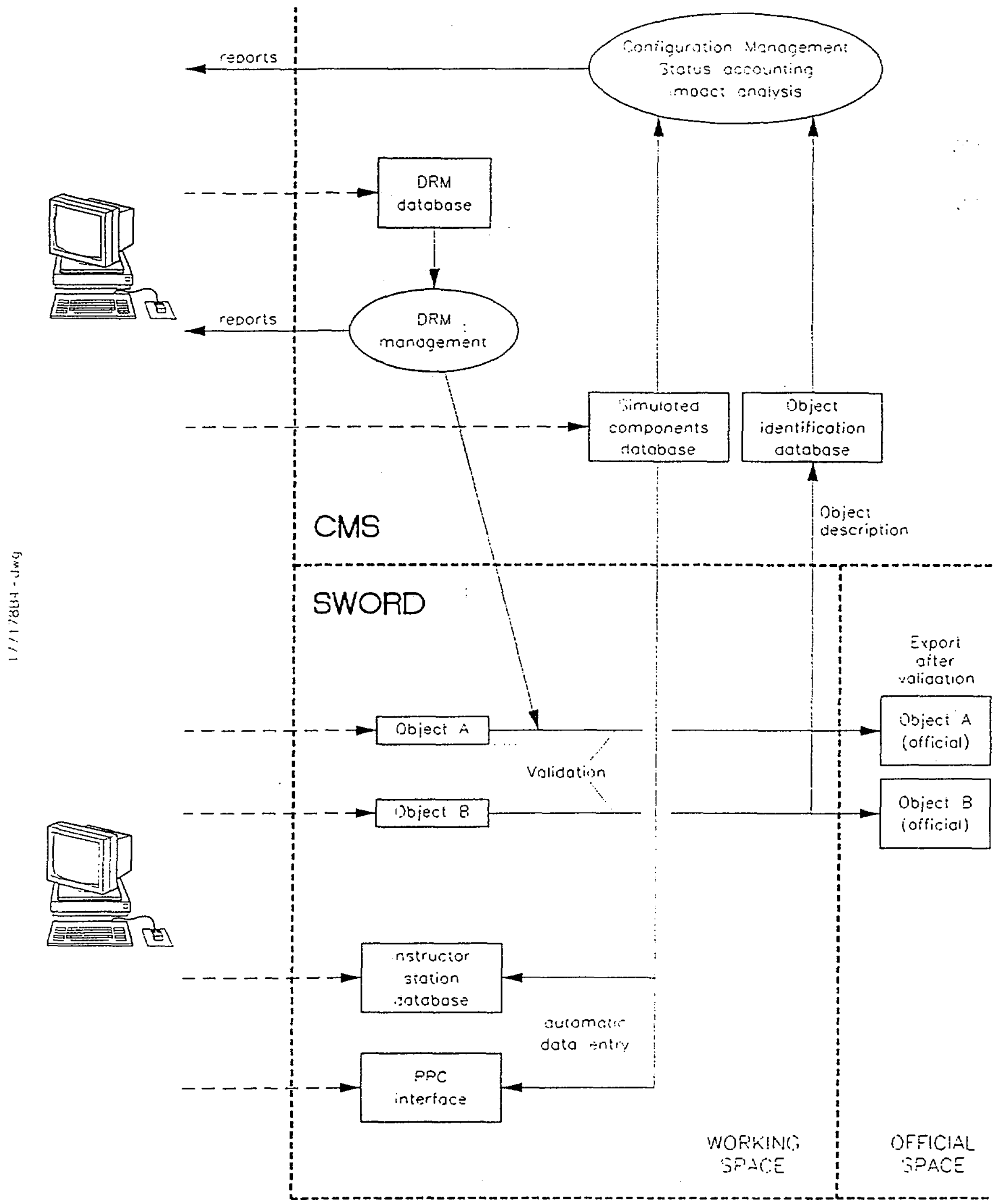
- establishing and maintaining the simulator design data base.
- identifying, documenting, and tracking the differences between the simulator and its reference unit.
- managing the documentation for simulator testing and maintenance.

6.2.1 CMS Functional Structure

The CMS is organized around a dedicated relational database. This database is applied by its four functional components:

- **Configuration Item Manager.** This component manages all configuration items, including the man-machine interface. It supplies the tools for the following tasks :
  - impact analysis,
  - status accounting,
  - SWORD interface,
  - interactive update of configuration items.
- **Discrepancy Report Manager.** This component manages Problem/Change Reports and the associated Change Forms.
- **Documentation Generator.** This component automatically generates chapters of the design documentation, on the basis of the CMS or the SWORD databases. More importantly, it also tracks and identifies those documents for which theses standard chapters require updating by reason of any given modification.
- **I/O Manager.** This component establishes the I/O list for the Control Room.

The main data flows between CMS and SWORD are represented in Figure 4.



DRM = Discrepancy Report Management

Figure 4 - Main flows between CMS and SWORD

7. REFERENCES

[1] H. ZERBINO, 3D Core Model for Simulation of Nuclear Power Plants: Requirements, Model Features and Validation, Proceedings of the 2nd CSNI specialist meeting on simulators and plant analysers (1997), Espoo, Finland.

[2] G. OUDOT et al., CP0 Nuclear Power Plant Full-Scope Replica Simulators, Proceedings of the SCS 1997 Simulation Multiconference, Atlanta, Georgia, USA.

[3] G. OUDOT, Visualization Systems for Power Plant Simulation, Proceedings of the 1994 SCS Simulation Multiconference, San Diego, California, USA.

[4] C. DUFRENE, M. JACOLOT, F. POIZAT, Nuclear Reactor Simulators : EDF Experience and Projects, Proceedings of the 1995 SCS Simulation Multiconference, Phoenix, Arizona, USA.