Laguna Verde Simulator : A New TRAC-RT Based Application

Juan Jose Muñoz Cases

Agustin Tanarro Onrubia

TECNATOM S.A.

Avda. Montes de Oca, 1 – 28709 San Sebastián de los Reyes (MADRID-SPAIN)

Keywords : Laguna Verde NPP, TECNATOM, TRAC-RT, NEMO

Abstract

In a partnership with GSE Systems, TECNATOM is developing a full scope training simulator for Laguna Verde Unit 2 (LV2). The simulator design is based upon the current "state-of-the art technology" regarding the simulation platform, instructor station, visualization tools, advanced thermalhydraulics and neutronics models, I/O systems and automated model building technology.

When completed, LV2 simulator will achieve a remarkable level of modeling fidelity by using TECNATOM's TRAC-RT advanced thermalhydraulic code for the reactor coolant and main steam systems, and NEMO neutronic model for the reactor core calculations. These models have been utilized up to date for the development or upgrading of nine NPP simulators in Spain and abroad, with more than 8000 hours of training sessions, and have developed an excellent reputation for its robustness and high fidelity.

TRAC-RT BASED LV2 SIMULATOR MAIN FEATURES AND CAPABILITIES

Laguna Verde Unit 2 is a General Electric design Boiling Water Reactor BWR/5, owned by CFE and located on the coast of the Gulf of Mexico, in the state of Veracruz in Mexico.

Starting June 2003, TECNATOM and GSE Systems are engaged in the development of a full scope replica simulator for this plant.

To effectively meet the criteria contained in the LV2 simulator project specification, a "state of the art" simulation solution is used based upon an open architecture computing plataform Windows NT based. This will allow for integration to other third party/commercially available tools and software packages available from the software industry.

The simulator is to be primarily used by the licensee as a training device supporting a systematic program for training and licensing operators in the safe and efficient operation of the Laguna Verde units, and to provide for periodic refresher training and recertification. The simulator shall be used to train plant operators in all aspects and phases of normal, abnormal and emergency operation (via the plant control room and shutdown panels) of control manipulations, protection features, process systems, and associated auxiliary systems of the Laguna Verde units.

LV2 simulator shall be capable of introducing malfunctions and emergency situations requiring operator actions and/or observance of automatic system actions. In addition, the simulator shall be designed to have sufficient fidelity to serve not only as a training and licensing device, but also to support various other tasks important to CFE. Among these tasks are engineer training, licensed operator classroom instruction, engineering evaluations of planned modifications, and plant procedure verification and validation.

To accomplish the scope, reliability and accuracy requirememnts of the simulator specification, TECNATOM´s TRAC-RT thermalhydraulic code has been utilized for the reactor coolant and main steam system parameter calculations, and the neutronic program NEMO as core neutronics and instrumentation modelling tool.

TRAC-RT is a true six-equations thermalhydraulic engineering and simulation code that has been extensively validated against various NPP designs and test facilities. NEMO is a 3D neutronics code made available from a joint cooperation project between TECNATOM and Combustion Engineering. The combination of both programs produce very reliable and accurate results over the entire range of normal, abnormal and emergency plant operating conditions.

In addition, a MAAP-4 based severe accident module is being incorporated to the simulator modelling package, in order to extend its modelling scope to beyond design accident conditions.

TRAC-RT BACKGROUND

TRAC-RT (Transient Reactor Analysis Code – Real Time) is an advanced version of TRAC 'best-estimate' thermalhydraulic code series for simulation of transients in NPP's, adapted by TECNATOM for being implemented into NPP training and engineering simulators. To meet these objectives, TRAC-RT combines the accuracy and reliability levels of best-estimate engineering thermalhydraulic codes with the velocity and flexibility needed for training simulation purposes. In addition, a remarkable number of additional models and features, not usually included in best estimate engineering codes, have been also implemented into TRAC-RT based simulators to cover their specified scope and the full range of conditions potentially arising within the simulation scenarios.

Supported by nearly two decades of sustained improvement and scope extension and tested and validated through its implementation and use in a significant number of NPP full scope simulators covering different plant designs and technologies, TRAC-RT is a consolidated best-estimate simulation tool.

While maintaining real-time performance, TRAC-RT full-scope simulation of nuclear power facilities allows the simulator to achieve :

- Full plant modelling capability (modelled system scope) : in addition to the continuously increasing sizes and level of detail of the plant models developed for TRAC-RT, the complete interactivity of the code as Nuclear Steam Supply System (NSSS) simulation program allows it to be connected to Balance of Plant (BOP) and auxiliary system models covering up to the whole plant.
- Complete phenomenology modelling (physical simulation scope) : all relevant thermalhydraulic phenomena taking place in the modelled system are addressed, including those associated to normal operating conditions and manoeuvres, from shutdown to power operation, and accidental scenarios up to the core melt initiation.
- Complete control and instrumentation modelling (input-output access scope) : all the instrumentation signals and active component controlling devices associated to the control room and specified remote panels are addressed.

These features have been implemented up to date into NPP simulators with different man-machine interface concepts (control room replica or interactive graphic simulators), scope (basic principles, part scope or full scope), objectives (training or engineering) and reference NSSS technologies (PWR, BWR, ABWR, WWER, PHWR).

Since the initial real-time code version development, continuous exploitation of TRAC-RT based simulators, some of them belonging also to TECNATOM, has represented the best feedback for the code maintenance and enhancement process. In this way, TRAC-RT evolution is the result of the combined effort and experience of a team covering all the simulator life stages : specification, development, exploitation, maintenance and updating, which has allowed simulation shortcomings and needs along with potential scope enlargement issues being detected and evaluated, and the most suitable solution being proposed, analyzed, tested and implemented.

LAGUNA VERDE MODEL FOR TRAC-RT

Laguna Verde Nuclear Boiler Assembly model for TRAC-RT implemented into the simulator (Figure 1) includes the following systems :

- Reactor Pressure Vessel (B13) : Reactor vessel and internals (jet pumps, steam separators and dryers and core support structures)
- Fuel (J11) : Fuel channel thermalhydraulic model (nuclear power distribution calculated by NEMO)
- Reactor Recirculation System (B35B) : Pumps, valves and piping outside the reactor pressure vessel used in providing and controlling core flow
- Nuclear Steam System (B22) : Valves and piping from reactor pressure vessel up to and including the isolation valves outside of the primary containment barrier
- Main Steam System (N11) : Valves and piping from the isolation valves outside of the primary containment barrier up to and including the steam header

TRAC-RT based model interactive coupling with the rest of the plant system models is accomplished by means of specific boundary conditions (power, pressure, temperature, mass flow rate) defined within the model. In addition, active component actuations (valves, pumps, heaters, etc.) and malfunctions (breaks, system disturbances, etc.) are implemented through a complete access capability to any code internal variable, which allows to externally control the involved model parameters (model flow areas, active component performance parameters, etc.).

Main features of LV2 model for TRAC-RT are :

- Number of components : 139
- Number of junctions : 157
- Number of cells (TH control volumes) : 30 (3D) ; 156 (1D)
- Number of boundary conditions : 63

Reactor Pressure Vessel is primarily modelled through TRAC-RT provided 3D VESSEL component, properly connected to several 1D components to address specific RPV internal elements modelling, namely the fuel assemblies, jet pumps, steam separators and guide tubes. The rest of the internal structures (shroud, top guide, core plate, shroud head and steam dryer assembly), associated flow paths and heat transmission paths are specified through the VESSEL component defining input parameters.

From the thermalhydraulic point of view, the reactor core is modelled by a combination of TRAC-RT CHANNEL components. Nuclear power and power distribution are calculated by the neutronic model (NEMO) coupled to TRAC-RT CHANNEL model, and deposited into the fuel rods to be addressed by the models.

All 444 fuel assemblies in the real plant are lumped into 4 CHANNEL components. The CHANNEL components are based on the geometry of fuel assembly design GE12.

Connections associated to models beyond TRAC-RT model scope (FW, HPCS/LPCS, LPCI, RCIC, vessel head vent and spray) are coupled to flow boundary conditions governed by the associated system models according to the donor cell approach.

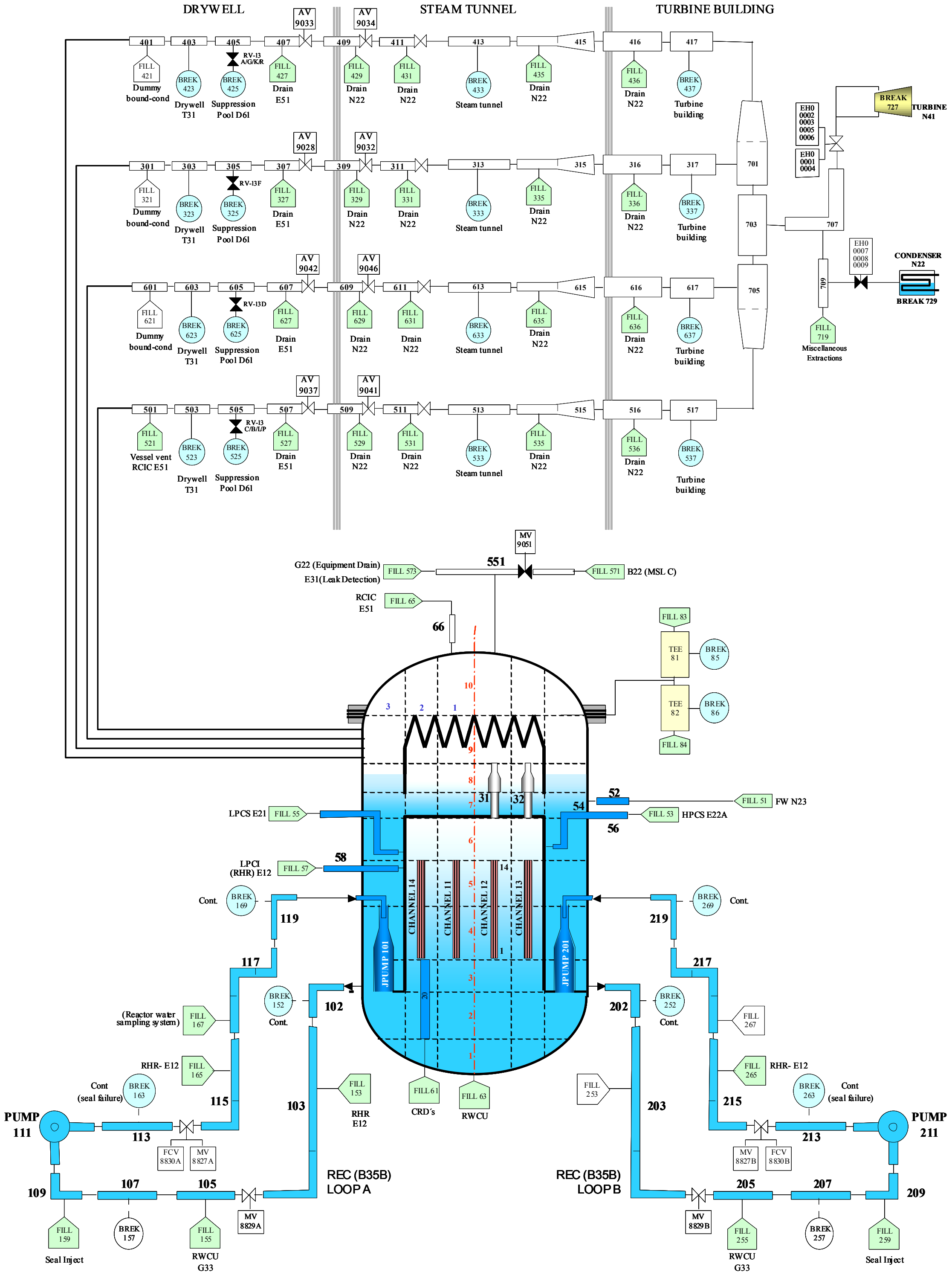

Figure 1 : LV2 model for TRAC-RT nodalization

NEUTRONIC MODEL (NEMO)

The reactor core neutronic model is designed to provide a realistic response as regards the processes taking place in the reactor core and observed via the nuclear instrumentation, as well as the core processes directly related to interaction with other plant simulation models. The two main functions of the Reactor Core Model (CR), modelled by NEMO code, are:

- To provide core power level and 3-D power distribution for TRAC-RT core model
- To provide appropriate signals for the simulator nuclear instrumentation system (NM)

The neutronic model calculates:

- The three-dimensional distribution of the neutron flux throughout the entire plant operation, under both normal and accident situations
- Total core power due to fission, including decay heat, for TRAC-RT core model
- 109 radial nodes, each one defined as one mesh node made of 4 fuel bundles and 1 control rod
- 109 control rods

To avoid a high CPU time consumption, the 109 radial neutronics nodes are combined in four radial thermalhydraulic nodes associated to the four CHANNEL elements defined in the model for TRAC-RT.

The three-dimensional neutron model calculates the neutron flux distribution with sufficient resolution to produce adequate signals for the nuclear instrumentation :

- 8 SRNM detectors
- 96 LPRM detectors located at four predetermined elevations along the core
- 4 APRM channels
- 2 RBM channels
- 4 OPRM channels

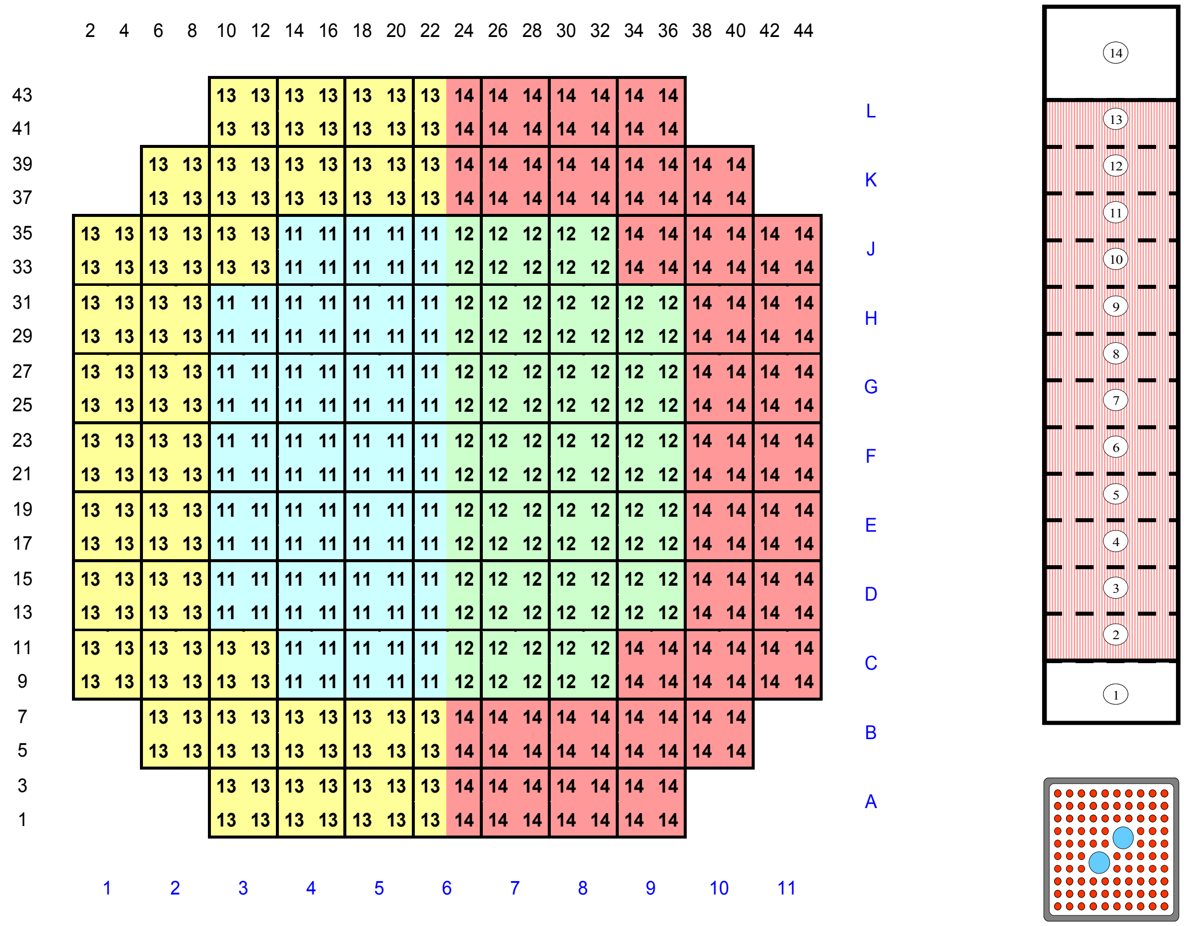

Figure 2 : LV2 model for TRAC-RT / NEMO core nodalization (CHANNEL component)

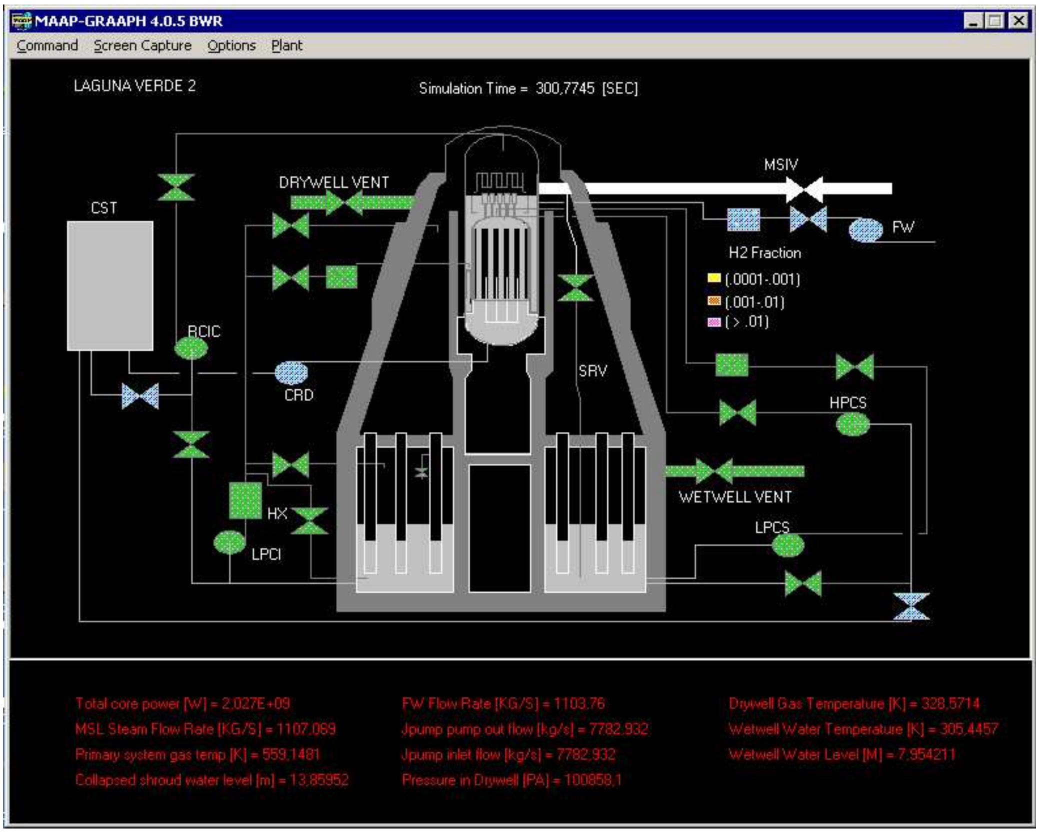

Figure 3 : LV2 model for MAAP-4 basic screen (MAAP-GRAPH)

LAGUNA VERDE SIMULATOR ADDITIONAL CAPABILITIES

In addition to the TRAC-RT based NSSS model, TECNATOM is developing a MAAP 4 based severe accident module for being used in specific simulator training sessions. This module, called 'Containment Advanced Model' (MAC), will enhance the simulator scope to cover the severe accident associated phenomenology, both in the primary system and the containment environment.

Severe accident sequences resulting in the eventual loss of the core geometric integrity have been found to have a small probability of occurrence in real plants but, because of the potential consequences to public health and safety, an evaluation of the core degradation progression and the resulting effects on the containment is necessary to determine the probability of a significant release of radioactive materials. In addition, proper countermeasures and actions must be defined, analyzed and compiled in the plant specific accident management guidelines.

Severe accident associated phenomenology encompasses the physical and chemical process involved in the main stages of beyond design accident scenarios, including :

- initiating events.
- core uncovery and heatup
- cladding material oxidation and hydrogen generation
- cladding failure and fission product release
- cladding, control rod and structural material melt and relocation
- pellet stack collapse and debris bed formation and relocation
- pressure vessel failure mechanisms
- in-containment involved phenomena : direct containment heating, steam explosions, hydrogen burn, core-concrete interaction, fission product and aerosol release, etc
- containment early/late failure mechanisms

The approach for the severe accident module implementation is based upon a special set of initial conditions allowing the switching of the core, reactor recirculation, pressure vessel thermohydraulics, and containment models to the MAAP simulation model interfaces. Although MAAP code does not completely model core neutronics and thermohydraulics, it provides sufficient modeling to initiate an accident sequence from full power with subsequent core degradation with very good results for degraded core, containment, and radioactivity parameters.

LV2 model for MAAP-4 has been built by introducing the plant specific data in the BWR 5/Mark II generic topology defined within the code. This model includes the reactor vessel and the primary containment (pedestal, drywell, wetwell and downcomers). Steam lines and recirculation loops are funtionally modelled

For those scenarios in which the above mentioned conditions are intended to be simulated, TRAC-RT based RCS model and auxiliary primary containment models will be replaced by the associated MAAP input deck., and MAAP model will run interactively with the remaining simulator models, through the dedicated interface scheme.

In this way, simulator capabilities are enhanced by allowing it to be used for the evaluation and validation of the plant specific severe accident management guidelines (SAMG), and to support related training sessions for the involved personnel (operators, Technical Support Center and managers).

JAVI graphical user interface

JAVI glass model monitor for TRAC-RT and NEMO is a new visualization tool for the graphic display of selected variables and parameters associated to the NSSS and core models. Values of these variables are displayed through a number of dynamic user configured graphic screens, which are defined over fixed templates representing the nodalizations of the plant models.

Being JAVI an independent module within the TRAC-RT/NEMO execution environments, it may be activated and used from any other associated application (instructor console, debugger, engineering station, etc.) connected to the simulation server in which TRAC-RT/NEMO based calculations are executed, both in real-time (simulator) or off-line mode (engineering station).

TRAC-RT ASSOCIATED LATEST DEVELOPMENTS AND IMPROVEMENTS

Several activities aimed to the continuous improvement and updating of TRAC-RT capabilities and applications are on course, among them :

ANSI steam tables implementation

TRAC code internal thermodynamic properties routines are to be replaced by the ANSI steam tables, in order to enlarge the variable values range addressed and get more accurate and reliable results.

METRANE project

Different activities are under development in the framework of the METRANE (TRAC-NEMO enhancement) project, including :

- physical model improvements (enhanced non-condensible gas treatment, level model, etc.)
- NEMO independent execution capability and input generalitation
- NEMO burnup cycles automatic generation procedure
- normalized tools for interface routines generation
- TRAC model maintenance and check auxiliary routines development

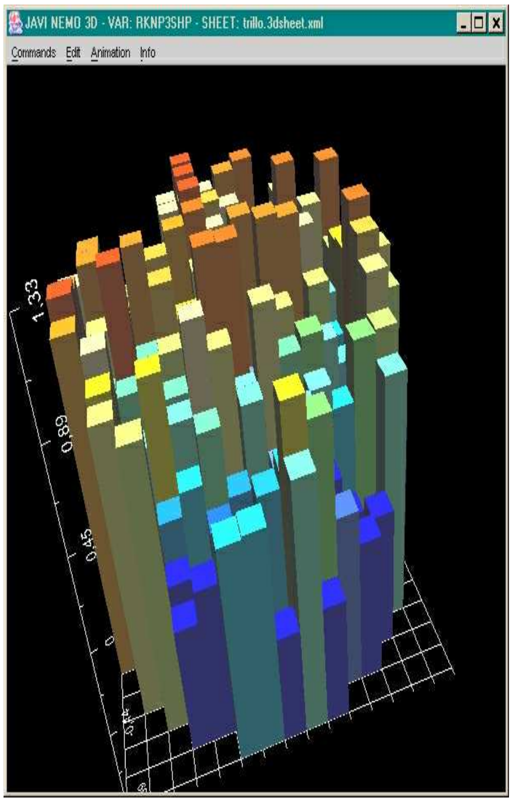

Figure 4 : JAVI core screen