# OTHER APPLICATIONS OF BEST-ESTIMATE CODES AND METHODOLOGIES IN ADDITION TO LICENSING

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**Together with their applications for purposes of licensing, best-estimate thermalhydraulic codes offer the possibility of a wide range of additional uses or applications in which the most realistic, reliable results possible are required. Although many of these applications have already been put into practice with satisfactory results, the use of these codes for purposes other than those associated to licensing processes is not as well known among the nuclear community in general. This article describes some of these applications and their most notable specific features.**

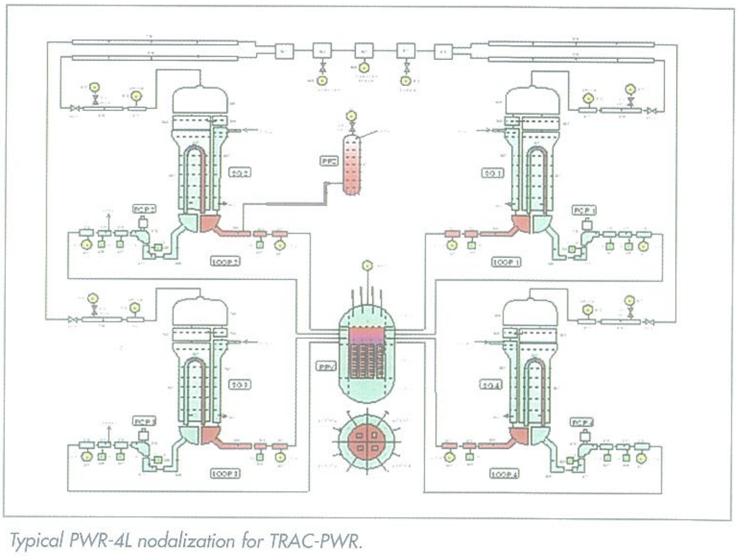
## INTRODUCTION

A best-estimate thermalhydraulic code is a computer program containing a complex set of mathematical models, the purpose of which is to calculate as realistically and accurately as possible the evolution of the major parameters involved in operational and accidental transients in thermalhydraulic installations in general and nuclear facilities in particular. Their scope, accuracy and degree of realism are determined by the theoretical knowledge and experimental data available on the different physical phenomena involved in these evolutions and by the available calculation methods.

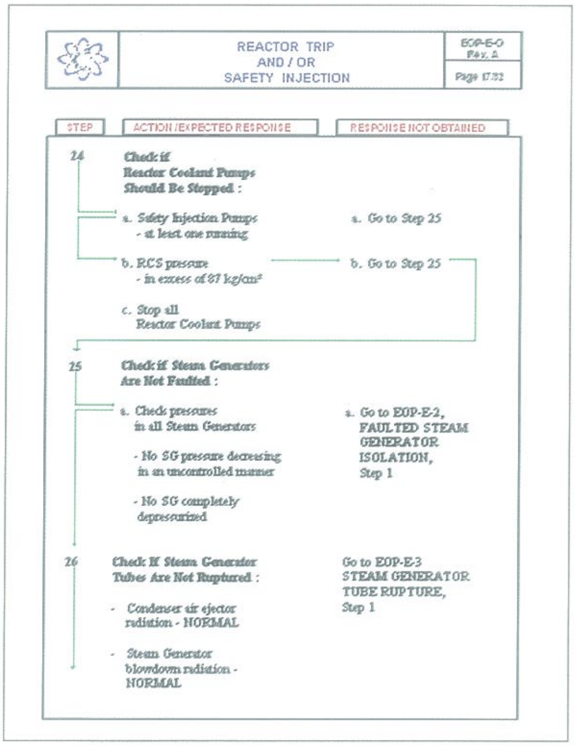
Best-estimate codes differ fundamentally from the so-called conservative codes in that the former are used to obtain realistic results, whereas the purpose of the latter is to obtain bounding envelopes of these results under conservative criteria for purposes of licensing.

The use of realistic calculation programs for licensing analysis has for many years been a controversial subject. On one hand, as indicated above, conservative codes and programs provide bounds in the conservative direction of the evolutions being considered, so that potential inaccuracies of the models should in all cases be contained within the resulting conservative margins. However, it is always possible that the very approach of supposedly conservative conditions and hypotheses could mask effects in the non-conservative direction that could be revealed in a realistic calculation. On the other hand, excessive conservatism when establishing operating margins, defined as the difference between the value of the main limiting parameters and the associated acceptance criteria, has an obvious economic impact on plant operation, as it imposes limits on plant operational factors that could, sometimes, be excessively restrictive. Therefore, for several years, regulatory bodies have tended to allow the use of certain "best-estimate" codes for licensing analysis, but with strict requirements in terms of assuring the reliability of the results which, in keeping with established acceptance trends, should be demonstrated by the corresponding uncertainty analysis on the basis of an approved methodology. Thus, regulatory requirements establish that the analysis should demonstrate that it is highly probable that the established criteria and limits set will not be exceeded even if the overall quantified uncertainty levels of best-estimate models are taken into account.

However, in addition to these applications for licensing purposes, best-estimate thermalhydraulic codes offer the possibility of a wide range of additional uses or applications in which realistic results are required and in which uncertainty analyses are generally not applicable. Although many of these applications have already been put into practice with satisfactory results, the use of these codes for purposes other than those associated to licensing processes is not as well known among the nuclear community in general. This article describes some of these applications, briefly discussing their most notable specific features and providing some examples.



*Typical PWR-4L nodalization for TRAC-PWR.*



| STEP | ACTION /EXPECTED RESPONSE | RESPONSE NOT OBTAINED |
|---|---|---|
| | REACTOR TRIP AND / OR SAFETY INJECTION | EOP-E-0 Rev. A Page 17/32 |
| 24 | **Check if Reactor Coolant Pumps Should Be Stopped :** | |
| | a. Safety Injection Pumps - at least one running | a. Go to Step 25 |
| | b. RCS pressure - in excess of 87 kg/cm² | b. Go to Step 25 |
| | c. Stop all Reactor Coolant Pumps | |
| 25 | **Check if Steam Generators Are Not Faulted :** | |
| | a. Check pressures in all Steam Generators<br>- No SG pressure decreasing in an uncontrolled manner<br>- No SG completely depressurized | a. Go to EOP-E-2, FAULTED STEAM GENERATOR ISOLATION, Step 1 |
| 26 | **Check If Steam Generator Tubes Are Not Ruptured :**<br>- Condenser air ejector radiation - NORMAL<br>- Steam Generator blowdown radiation - NORMAL | Go to EOP-E-3 STEAM GENERATOR TUBE RUPTURE, Step 1 |

*EOP evaluation example*

## EVALUATION AND ANALYSIS OF COMPONENT OR SYSTEM MODIFICATIONS

If a problem is identified or the possibility arises of improving a plant component or system, different technical solutions can be proposed that will involve modifications to the existing components or systems or incorporation of new ones. Best-estimate thermalhydraulic codes provide a very useful tool for the analyses associated both with the design of these modifications and their evaluation for selecting or prioritizing the different alternative proposals on the basis of effectiveness, cost and viability criteria. They supply valuable information to different phases of these processes, such as the following:

- preliminary assessment of the modification's effect on operating margins and, if acceptable, from the standpoint of applicable regulatory standards.

- check of potential adverse or unforeseen impacts on other components or systems involved.

- evaluation of the system's response when the modifications involve innovative designs regarding which there is little or no operational experience.

- determination of the proposed alternative solutions which are equally effective for fulfilling the established goals, which would justify basing the decision on cost and planning criteria.

This type of application has been used in several American (Point Beach, Haddam Neck) and European (Beznau, Doel) nuclear power plants to support specific projects for modifying systems or components or operating strategies and policies, and this has resulted in increased operating margins and reduced costs.

In Spain, a rigorous analysis using the RELAP 5/MOD 2 code and supported by the COBRA program results served to justify the fact that it was not necessary to incorporate the AMSAC (Automatic Mitigation System Actuation Circuit) system for ATWS (Anticipated Transient Without Scram) mitigation in the José Cabrera nuclear power plant, based on the sizing of certain plant components.

## DEVELOPMENT AND EVALUATION OF EMERGENCY OPERATION PROCEDURES

Within the general strategies for accident mitigation, Emergency Operation Procedures (EOPs) define how operating personnel should act when coping with abnormal or accident conditions. These actions should always be targeted at leading the plant to a stable and safe condition and minimizing the potential adverse consequences of the event.

Analyses with best-estimate codes concerning the development of emergency operation procedures include all calculations required for selecting and optimizing the recovery strategy, defining key variables to be monitored by the operator, providing data for setpoints or values of these variables to which the operator should react with a specific action, and in general supplying most of the specific plant calculations required for drawing up the EOPs.

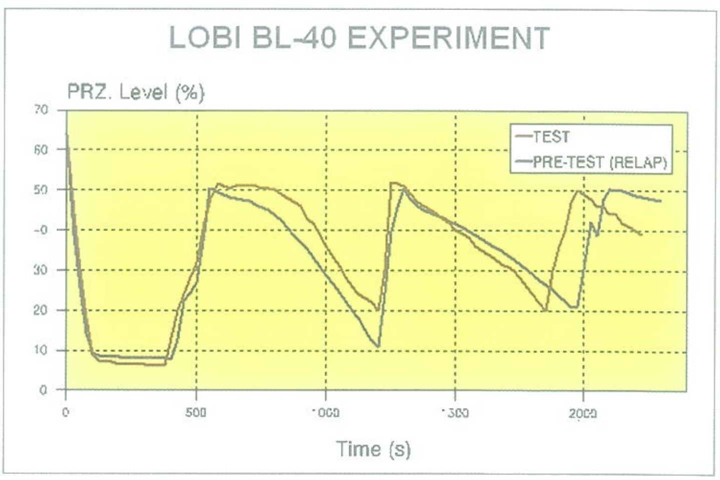
On the other hand, the primary purpose of support analyses for evaluating or validating EOPs is to determine that the actions specified in the procedures can be properly executed within a reasonable time frame by properly trained operators, and in general that accident management is viable and suitable and accomplishes the goal of taking the plant back to a stable, safe condition and minimizing the potential harmful consequences of the event.

This type of objective requires the analysis to address certain peculiarities, including the following:

- the need for a realistic approach becomes even more important in this case, as the purpose is to determine as specifically and accurately as possible the operator actions required to achieve optimum recovery in the face of real circumstances and their associated indications.

- it is essential that available instrumentation be properly modeled, and to establish or evaluate the checking, diagnostic or decision making steps in the procedures based only on the information that can be read or deduced from the indicators. If it is deemed advisable to base decision making on information provided by calculation and not available from process instrumentation, the possibility must be considered of deducing this information based on readings or alternative measurements of the instrumentation, or of even proposing that its scope be increased in the design.

- the operation and effect of systems or signals obtained from associated instrumentation must be addressed in the analyses, even though they are outside the model scope, considering them, if necessary, as boundary conditions or




*Measured and calculated pressurizer level (LOBI BL-40 experiment).*

assumptions for the calculation (e.g. consider the diagnosis of a steam generator tube rupture on the basis of a high radiation signal in the condenser, which is not normally evaluated by the models available in the codes).

- realistic hypotheses should be proposed concerning operators' reaction and action times, and if deemed advisable sensitivity studies should be carried out to evaluate time margins and determine the optimum procedure. This optimum procedure should address the human factors involved. In this respect, standard ANSI/ANS-58.8-1994 establishes that if, in the analyses, it is determined that the instrumentation systems and alarm processes do not provide the operator with enough time to take the actions required to mitigate the consequences of design base events before the established limits are exceeded, these actions should be automated, and then the problem becomes one of design.

- however, the recovery strategy should not be based on excessively conservative assumptions regarding the time frame of the operator's actions, considering longer than reasonable reaction times. Above mentioned standard ANSI/ANS-58.8-1994 establishes criteria for estimating operator response times in different scenarios and conditions, primarily based on measurements obtained in simulator sessions; they therefore can be considered as realistic references.

- as a last step in EOP preparation and validation procedures, it is advisable to reproduce the scenarios considered in best-estimate analyses in a replica simulator, in order to perform a combined "ergonomic validation" of these scenarios and the control room configuration.

TECNATOM has had some interesting experiences in this type of activity that have demonstrated the utility of these codes, such as support calculations with RELAP 5/MOD 2 for validating PWR plant EOPs, or evaluating the applicability range of Westinghouse's generic Emergency Response Guidelines (ERGs) to advanced reactor AP-600 by means of calculations with Westinghouse code TREAT-AN and with RELAP 5/MOD 3.

At present, within the framework of the European Community's TACIS and PHARE projects and other IAEA-sponsored projects, work is being done on adapting and improving the EOPs in force in Soviet-design plants (WWER and RBMK), replacing the "event-oriented" philosophy with the Western approach of "symptom-oriented" procedures. The support analyses for these projects use different versions of best-estimate codes.

## SAFETY ANALYSIS

Realistic thermalhydraulic codes are used for developing support calculations for a large number of analyses whose ultimate purpose is to evaluate a plant's safety levels, outside the area of licensing or even as a support for it. This kind of activity includes support calculations for Probabilistic Safety Analyses, which are discussed specifically in the next section, and many other calculations generally intended to analyze the plant's capacity for dealing with failures or malfunctions or the need for protection and safeguard systems, including redundancy levels, required systems operability (defined in the plant's Performance Technical Specifications), etc.

In view of the diversity of this type of calculations, it is not easy to define specific requirements and characteristics for them. Generally speaking, the following could be highlighted:

- the scope and range of applicability of the code used should be well defined and taken into account when using it for a particular analysis.

- the scope of plant models should be as broad as possible, so that the calculation can reflect the effect of or on systems other than those initially considered as the most significant systems for the postulated scenario.

- sensitivity analyses and calculation of alternative scenarios in which selected systems may or may not be involved can be essential depending on the postulated transient and the purpose of the analysis.

A large number of experiences can be mentioned in this area. For example, some of the work developed in TECNATOM along these lines includes:

- parametric studies with RELAP 5/MOD 2 of liquid carry-over and steam generator filling in a tube rupture accident.

- parametric analyses with RELAP 5/MOD 2 of the time it would take for the cladding temperature peak (dry-out) to occur in a PWR nuclear power plant in a postulated scenario of total loss of alternating current and for different assumed leak flows through the pump seals. The conclusions obtained from these analyses were used in the development of the Level 1 PSA of the plant.

## SUPPORT CALCULATIONS FOR PSA DEVELOPMENT

The purpose of the Probabilistic Safety Analysis (PSA) is to quantify the risk associated with a plant operation. Generally speaking, it establishes the different potential accident sequences and quantifies their probability, frequency and consequences.

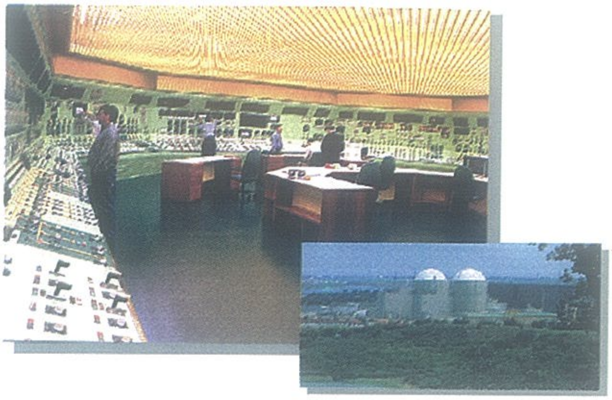
To develop the PSA, probabilistic models of the plant must be available. These models represent the response of each plant in terms of sequences of events caused by a proposed initiating event. The sequences represent the plant's response depending on the success or failure of the systems used for safety functions, and they are defined by the so-called failure trees.

The definition of failure trees includes the determination of success criteria, the chronological sequence of events, and the end states of the different sequences. These analyses use the results of calculations with severe accident codes, whose thermalhydraulic boundary conditions are often extracted from complementary calculations with best-estimate codes and methods. In other cases, programs that enhance the scope of best-estimate codes by providing them with the capacity to calculate core-damage situations are used (e.g., SCDAP/RELAP code). Finally, in some cases in which the usually simpler "thermalhydraulic packages" of severe accident codes are used (e.g., code MAAP), best-estimate thermalhydraulic codes are often used to qualify these packages and their associated models.

The typical characteristics of PSA support calculations with best-estimate thermalhydraulic codes include the following:

- the code's applicability range should include full and low power conditions and even outage situations, depending on the specific PSA scope.

- the boundary conditions will be defined by the PSA model. This means they must take into account the actuation and subsequent effect of safety systems, systems involved in normal operation, and operator actions that could play a role in transient or accident evolution.



Almaraz NPP full-scope replica simulator (TECNATOM S.A.)

- acceptance criteria should be defined by the PSA, depending on its scope (Level 1 or 2) as well as the end states of the postulated sequences. Level 1 PSA support is primarily based on quantification of the minimum equipment required to ensure core safety (success criteria) and collaboration in the area of human reliability (determination of time available to take mitigating actions in accident sequences before core degradation). For Level 2, analyses are performed to determine fuel damage times and mechanisms, to simulate accident management measures, etc.

## PERSONNEL TRAINING

Thermalhydraulic codes are very useful for personnel training activities, as they provide important capabilities for improving the effectiveness of the classroom training of each plant's specific training programs, including:

- generation of material for thermalhydraulic and accident analysis courses based on specific plant results.
- generation of data on evolution of the plant's most critical or relevant transients.
- On-line use of codes and associated models in training sessions with the support of graphic interfaces, such as the Nuclear Plant Analyzer (NPA) software for RELAP 5 or similar, which provide a conceptual vision of transient-related phenomenology.

## SIMULATOR DEVELOPMENT AND VALIDATION

Analyses of the industry's operating experiences show that most reported problems and incidents are related to human failures and errors. In view of this reality, suitable plant personnel training is becoming increasingly important and, in the specific case of operating personnel, this results in the need for applying simulation technologies that combine the necessary flexibility for analyzing the full range of plant conditions with a high degree of reliability in the realism and accuracy of the response obtained.

Current computational capabilities permit the use of certain best-estimate thermalhydraulic and neutronic codes as basic software for simulation devices. There are two major requirements for this application that, among others, should be fulfilled by these codes:

1. real-time execution throughout the training session's support calculations.

2. interactive feature, to allow interconnection to simulator hardware, graphic interfaces and auxiliary programs.

TECNATOM has extensive experience in adapting and applying best-estimate codes to training simulators, including both full-scope control room replica and interactive graphic simulators. This experience has been gained fundamentally from the application of real-time codes TRAC-PWR and TRAC-S to simulators in plants of differing technologies. These codes were developed by TECNATOM, with the collaboration of General Electric in the case of TRAC-S.

These applications include simulators of plants with American pressurized water (Almaraz NPP, Ascó NPP, José Cabrera NPP, Vandellós NPP) or boiling water (Cofrentes NPP) technology, or German light water and heavy water technology (Atucha NPP).

The NSSS model of the ABWR-type, General Electric-design Lungmen plant is currently under development for code TRAC-S, as well as the NSSS model of the PWR-4L type, KWU Grafenrheinfeld plant for code TRAC-PWR. The applicability of TRAC-PWR to WWER technology has also been evaluated, through the successful use of the code for post-test calculation of experiment SPE-4 in experimental facility PMK-2, the reference of which is the Hungarian Paks nuclear power plant.

On the other hand, verification and validation of training simulators requires that their response to scenarios and operating modes within the range of their scope be compared to realistic, reliable reference data. For this purpose, the records of the real reference plant are used as much as possible. However, because few severe accidents have been recorded in the nuclear industry, real data are not available for comparing simulator responses to these scenarios, but they nevertheless are essential in an operating personnel training program. This "deficit" is offset by results provided by best-estimate codes that calculate on the basis of specific models of the plant in question.

## TRANSIENT DEFINITION AND ANALYSIS IN EXPERIMENTAL FACILITIES

In addition to code assessment exercises based on preliminary or pre-test "blind" calculation of parameter evolution in experimental thermalhydraulic installations or on reproduction of the evolution recorded after the experiment or post-test calculation, thermalhydraulic codes are an essential tool for defining the experiment itself.

This is because a quantitative definition of all parameters and conditions contributing to the experiment's evolution before it is carried out requires realistic thermalhydraulic analyses to calculate and, if appropriate, optimize the values and trends of these parameters and variables, in order to dictate the most appropriate evolution for observing the phenomenology under study. The parameters and conditions to be determined include the following:

- total experiment time.
- time sequence.
- setpoints or actuation times.
- evolution of the main variables, including maximum and minimum values, especially when these affect the experiment's safety.
- the most appropriate conditions for the phenomenology to be observed and additional foreseeable phenomena.
- the experiment's viability based on the facility's characteristics and safety considerations.
- parametric and sensitivity analyses to support ad-hoc decision making during the experiment based on the observed evolution.

TECNATOM has gained experience in this field through its participation in pre-test calculations with RELAP 5/MOD 2 for defining and specifying experiment BL-40, developed in the Joint Research Center's LOBI facility in Ispra, Italy. This was an operated experiment intended to experimentally validate Emergency Operation Procedure E-3 for steam generator tube rupture in a Spanish plant. In addition to the analyses for specification of the experiment, several parametric sensitivity calculations were performed on the discharge coefficient of the valve representing the tube rupture, which served as the basis for ad-hoc decision making during the experiment.

## INSPECTION TEST DEFINITION AND ANALYSIS AND EVALUTION OF PREVENTIVE OR CORRECTIVE MAINTENANCE ACTIVITIES

Realistic thermalhydraulic calculation codes and programs can also be applied to other plant activities, such as inspection and maintenance. In the case of inspections, for example, analyses have been performed with this type of tool for the following:

- preliminary quantitative estimates of the magnitude of cracks or breaks based on measured or estimated values of flows, inventories, water levels, radiation levels, etc.
- definition or specification of inspection tests, determining the optimum values of imposed variables or parameters to obtain the best results for the variables to be evaluated, i.e. results within easily measurable ranges or imposed values to which the parameters to be measured are more sensitive.

In the case of maintenance, different plant departments may on occasion require engineering personnel to provide information on the effect of or the best conditions for performing some of their own activities, for example the following:

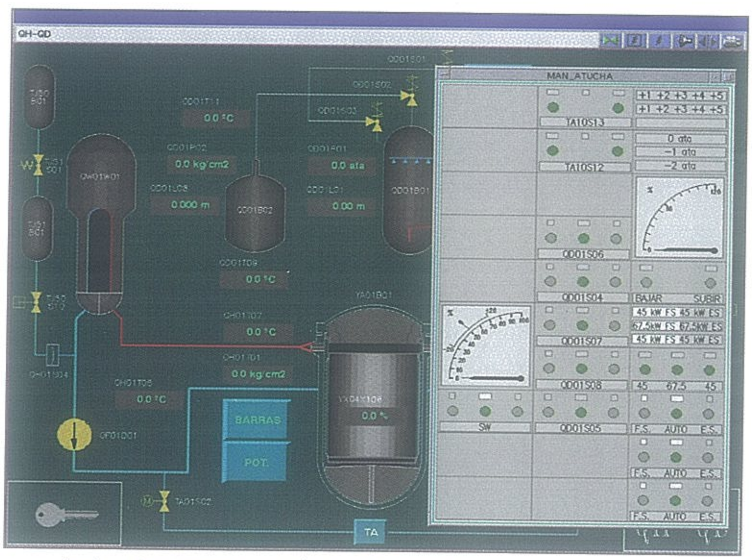
- estimation of the effect of certain activities on rated plant conditions, such as plugging of steam generator tubes.
- performance measurements.
- viability of tagouts and potential effects on operating margins under different plant conditions.

An example of this type of application are the sensitivity studies that TECNATOM has carried out with RELAP 5/MOD 3.2 code to evaluate the viability of certain inspection tests designed to measure fouling in steam generator tubes.

## FUTURE APPLICATIONS AND LINES OF DEVELOPMENT

Future applications of best-estimate thermalhydraulic calculation programs are closely linked to development of computation capability. Since today we could say that this development is evolving exponentially and that, on the other hand, any future short- and mid-term applications and uses will be significantly impacted by legal and administrative considerations regarding the commercial use of some of these programs, we can only refer here to personal forecasts and estimates. In this respect, and accounting also for current developments, current or proposed lines of research and the requirements and demands of the different markets involved, we can anticipate the following lines of development:

- continued development of more comprehensive, accurate physical models, e.g. more extensive use of three-dimensional models of both thermalhydraulic and neutronic phenomena.
- optimization and enhancement of numeric methods.
- hardware- or software-based acceleration of programs, e.g. by means of parallelization processes.
- enhanced graphic interfaces.
- growing application of best-estimate programs to real-time simulation.
- connection of this type of software to actual plant process computers and instrumentation for on-line initialization systems of simulators and codes.
- in line with the above, predictive models executing faster than real time.



*Atucha-1 NPP Interactive Graphic Simulator display*

## CONCLUSIONS

On the basis of the fields of application and examples described above, it is deduced that the range of application of the so-called best-estimate thermalhydraulic codes extends beyond their exclusive use for licensing analysis. The applications discussed, along with many others that could be developed, are based precisely on the best-estimate nature of these programs, which consists not only in the ability to provide realistic results (as opposed to the conservative results of licensing and safety codes used until recently), but also to constitute programs whose scope is based on the most advanced existing knowledge and available data regarding the physical phenomena that they model and on the calculation methods development status (the so-called 'state of the art').

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