ROLE OF RELAP/SCDAPSIM IN RESEARCH REACTOR SAFETY

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ABSTRACT

The RELAP/SCDAPSIM code, designed to predict the behaviour of reactor systems during normal and accident conditions, is being developed as part of the international SCDAP Development and Training Program (SDTP). SDTP consists of more than 60 organizations in 28 countries supporting the development of technology, software, and training materials for the nuclear industry. The program members and licensed software users include universities, research organizations, regulatory organizations, vendors, and utilities located in Europe, Asia, Latin America, Africa, and the United States. Innovative Systems Software (ISS) is the administrator for the program. RELAP/SCDAPSIM is used by program members and licensed users to support a variety of activities. The paper provides a brief review of the applications of the code to the simulation and analysis of research reactors in the United States, Europe, Asia, and Africa. An example showing the application of the code to the SAFARI-1 research reactor in South Africa for licensing analysis and for use in an operator training simulator (SAFSIM) is included in the paper.

1.0 Introduction

The RELAP/SCDAPSIM code, designed to predict the behaviour of reactor systems during normal and accident conditions, is being developed as part of the international SCDAP Development and Training Program (SDTP) [1,2]. SDTP consists of nearly 60 organizations in 28 countries supporting the development of technology, software, and training materials for the nuclear industry. The program members and licensed software users include universities, research organizations, regulatory organizations, vendors, and utilities located in Europe, Asia, Latin America, Africa, and the United States. Innovative Systems Software (ISS) is the administrator for the program.

Three main versions of RELAP/SCDAPSIM, as described in Section 2, are currently used by program members and licensed users to support a variety of activities. RELAP/SCDAPSIM/MOD3.2 and MOD3.4 are production versions of the code and are used by licensed and program members for critical applications such as research reactor and nuclear power plant applications. The most advanced production version, MOD3.4, is also used for general user training and for the design and analysis of severe accident related experiments such as those performed in the Phebus and Quench facilities. In turn, these experiments are used to improve the detailed fuel behaviour and other severe accident-related models in MOD3.4 and MOD4.0. MOD4.0 is currently available only to program members and is used primarily to develop advanced modelling options and to support graduate research programs and training. Section 3 highlights various research reactor applications. An example showing the application of the code to the SAFARI-1 research reactor in South Africa for licensing analysis and for use in an operator training simulator (SAFSIM) is included.

2.0 RELAP/SCDAPSIM

RELAP/SCDAPSIM uses the publicly available RELAP/MOD3.3[3] and SCDAP/RELAP5/MOD3.2[4] models developed by the US Nuclear Regulatory Commission in combination with proprietary (a) advanced programming and numerical methods, (b) user options, and (c) models developed by ISS and other members of the SDTP. These enhancements allow the code to run faster and more reliably than the original US NRC codes. MOD3.4 and MOD4.0 can also run a much wider variety of transients including low pressure transients with the presence of non-condensable gases such as those occurring during mid-loop operations in LWRs, in pool type reactors, or in spent fuel storage facilities.
The most advanced version of the code, RELAP/SCDAPSIM/MOD4.0[5], is the first version of RELAP or SCDAP/RELAP5 completely rewritten to FORTRAN 90/95/2000 standards. This is a significant benefit for the program members that are using the code for the development of advanced models and user options such as the coupling of the code to other analysis packages. Coupled 3D reactor kinetics and coupled RELAP/SCDAPSIM-SAMPSON [6] calculations are examples where MOD4.0 is used because of a significant reduction in the code development effort and expense to link the packages. MOD4.0 also includes advanced numerical options such as improved time advancement algorithms, improved water property tables, and improved model coding. As a result the code can reliably run complex multi-dimensional problems faster than real time on inexpensive personal computers. Plant simulation and integrated uncertainty analysis are among the most important applications benefiting from the improved speed and reliability of MOD4.0. MOD4.0 includes many enhanced user options to improve the accuracy of the code or to offer new options for the users. For example, the addition of an alternative material property library designed for Zr-Nb cladding materials is important for VVER and CANDU reactor designs, particularly for severe accident related transients. The addition of an advanced water property formulation is important for many transients, in particular those involving super critical water applications.

3.0 RESEARCH REACTOR APPLICATIONS

A combination of RELAP/SCDAPSIM/MOD3.2 and MOD3.4 is being used to analyze research reactors. A brief summary of the early work by several countries was given in Reference [6]. The research reactors noted in this paper include (a) the LVR-15 reactor located at the Nuclear Research Institute in Rez, Czech Republic, (b) the CARR reactor being built in Beijing, China by the China Institute of Atomic Energy, and (c) TRIGA reactors located at the Atomic Energy Research Establishment in Dhaka, Bangladesh and National Nuclear Energy Agency in Bandung Indonesia. LVR-15 is a light-water moderated and cooled pool type reactor with a nominal thermal power of 15 MW. The pool operates at atmospheric pressure with an average coolant temperature in the core of 320 K. The reactor also has closed high pressure/temperature loops suitable for testing of materials under PWR and BWR conditions. The reactor core is composed of several fuel assemblies of Al-U alloy arranged in square concentric tubes. CARR is a tank-in-pool design, cooled and moderated by light water and reflected by heavy water. The rated power is 60 MW. The core consists of plate-type fuel assemblies of Al-U alloy. The Indonesian and Bangladesh TRIGA reactors are pool type reactors with 2 MW and 3 MW thermal power respectively. The reactor cores are composed of solid U-ZrH fuel rods arranged in a hexagonal array and are cooled by water in either forced or natural circulation, depending upon the conditions.

More recently, the analysis of two additional reactor types have been reported in References 7-9. The first is for the SAFARI-1 research reactor located in South Africa [7,8]. The second is the University of Missouri Research Reactor located in the United States [9]. The SAFARI-1 research reactor is a tank-in-pool type reactor operated at a nominal core power of 20MW. The core is cooled and moderated by forced circulation of light water. The reactor core can be operated in a variety of configurations from 24 to 32 fuel assemblies. Figure 1 shows an example of one such configuration. The fuel is U-Si-Al plate-type fuel elements. MURR is a 10 MW pool type reactor design with a pressurized primary coolant loop to cool the fuel region. The pressurized primary system is located in a pool allowing direct heat transfer during normal operation and transition to natural convection under accident conditions. The reflector region, control blade region, and center test hole are cooled by pool water (natural convection).

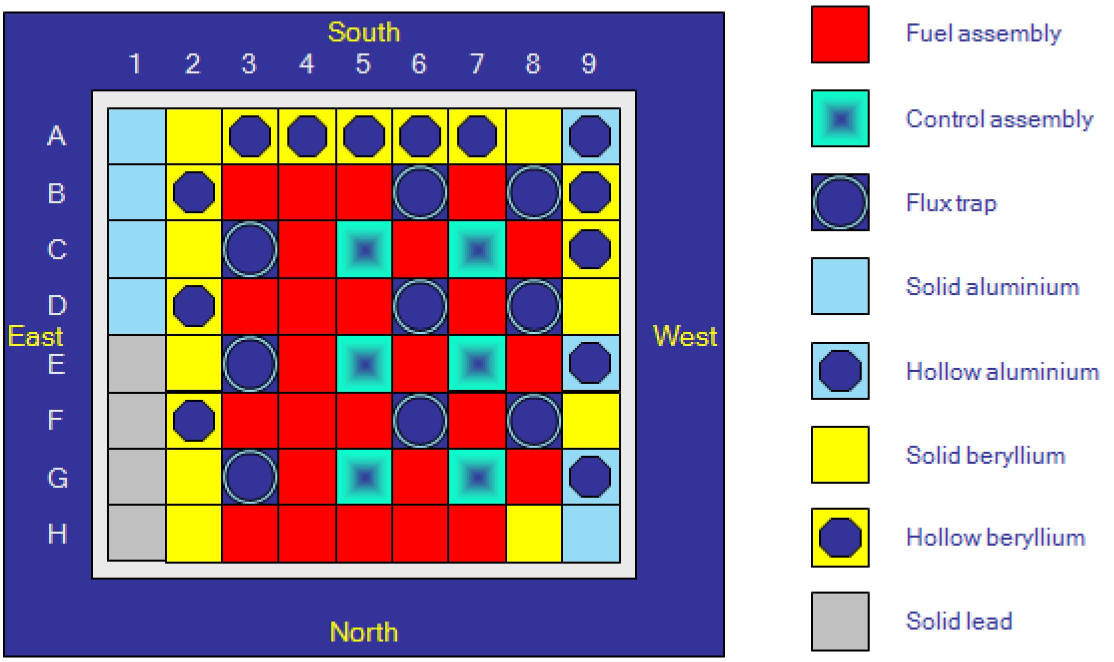

Figure 1: SAFARI-1 Reactor Core Configuration.

Because of the unique reactor designs, the RELAP/SCDAPSIM input models were developed separately by each organization and include a range of different nodalizations as presented in the reference papers. However in general terms, the RELAP/SCDAPSIM input models include all of the major components of each reactor system including the reactor tank, the reactor core and associated structures, and the reactor cooling system including pumps, valves, and heat exchangers. The secondary sides of the heat exchanger(s) are also modelled where appropriate. These input models were qualified through comparison with reactor steady state data, with original vendor safety analysis calculations where available, and with experiments in a limited number of cases.

Figure 2 shows the nodalization used for the SAFARI-1 research reactor. The figure shows the overall system hydrodynamic nodalization with the upper right corner of the figure showing the core nodalization. Note from the insert of the core nodalization diagram that the bypass or unheated channels were modelled separately from the heated fuel assembly channels. The core nodalization also included two separate hot plate channels located on each side of the hottest plate.

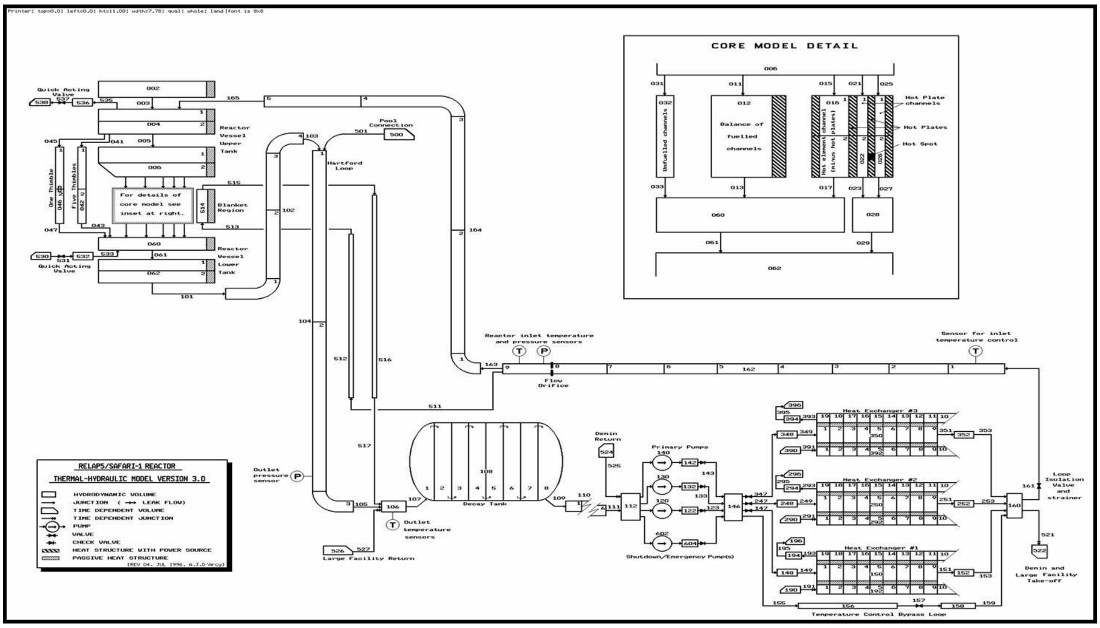

Figure 2: RELAP/SCDAPSIM Nodalization of the SAFARI-1 Cooling System.

A wide variety of transients have been analyzed using the code. Examples are included in the references and include reactivity initiated power excursions and loss of flow or coolant transients.

RELAP/SCDAPSIM/MOD3.4 is used as the simulation engine for the SAFSIM PC based training simulator for SAFARI-1. The simulator is used as a training tool for reactor operators. The main purposes of the simulator is to 1) build operator experience, 2) provide operator training at all levels, 3) be a pre-examination for licensed operators, 4) train personnel in the setup of operating modes, 5) develop operating and emergency procedures, 6) analyze operating incidents and occurrences and 7) give the operator a general understanding of reactor behaviour under all sorts of fault and accident conditions. Figure 3 shows the simulator running on a typical PC with dual monitors. Figures 4a and 4b show more detailed pictures of portions of the control panel mimic. As shown by comparison to photographs of the SAFARI-2 control room panel, figures 5a and 5b, the SAFSIM represents the main features of the control room control panel and provides a visually realistic image for training purposes.

At startup SAFSIM displays the reactor control room with the reactor completely shut down and the power supply to the protection mimic switched off. Therefore it is necessary for the trainee to go through the startup of all systems before the reactor can be started. The simulator was designed to give a realistic representation of the reactor and includes a very detailed representation of the reactor's control system using a combination of standard RELAP5 control systems and reactor-specific coded algorithms which are linked to RELAP5 for the simulator. As a result, new operator training or operator retraining, which originally required the actual startup and operation of the reactor, can now be done on the simulator. The simulator also has an instructor's panel from which the instructor can give the operator in training operational problems and challenges during a simulator session. Figure 6 shows the instructor's panel display.

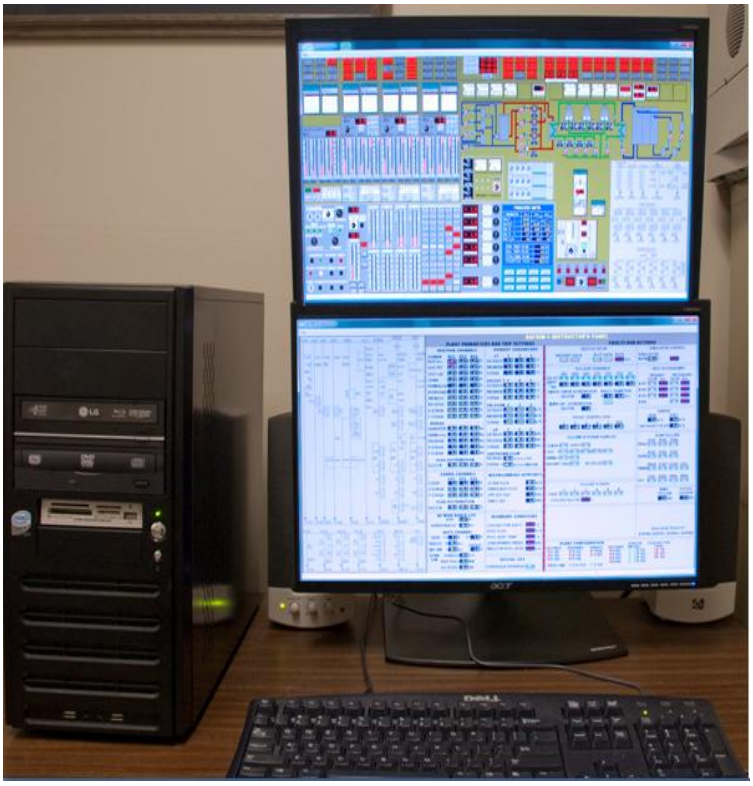

Figure 3: SAFSIM running on typical PC with dual monitors.

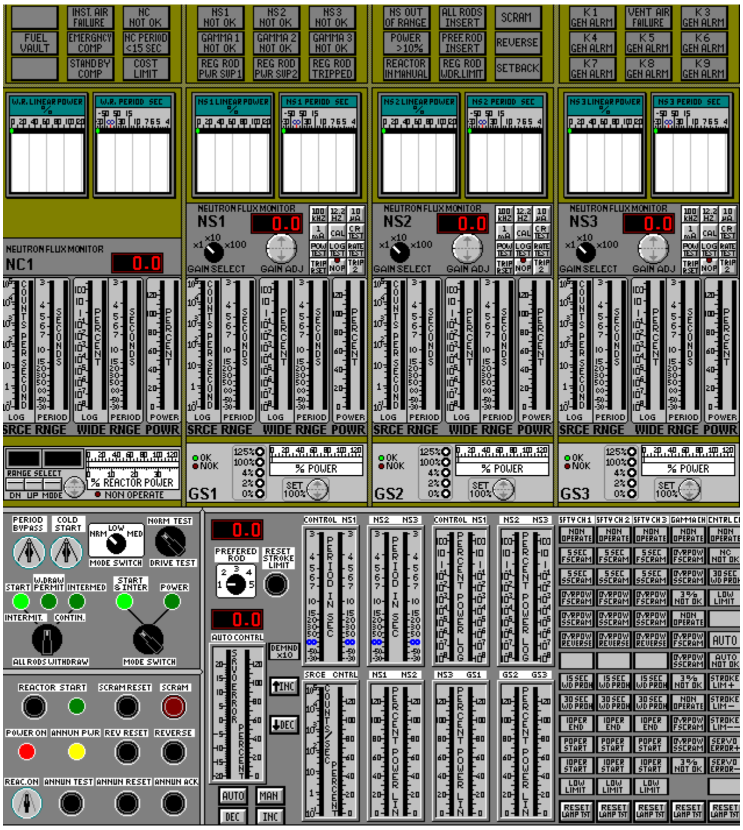

Figure 4a: Control panel mimic.

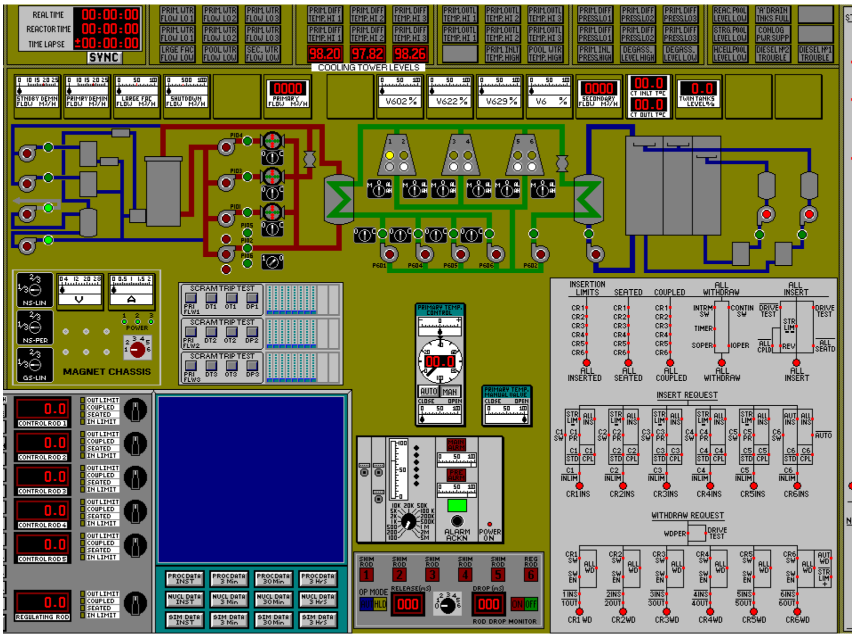

Figure 4b: Control panel mimic.

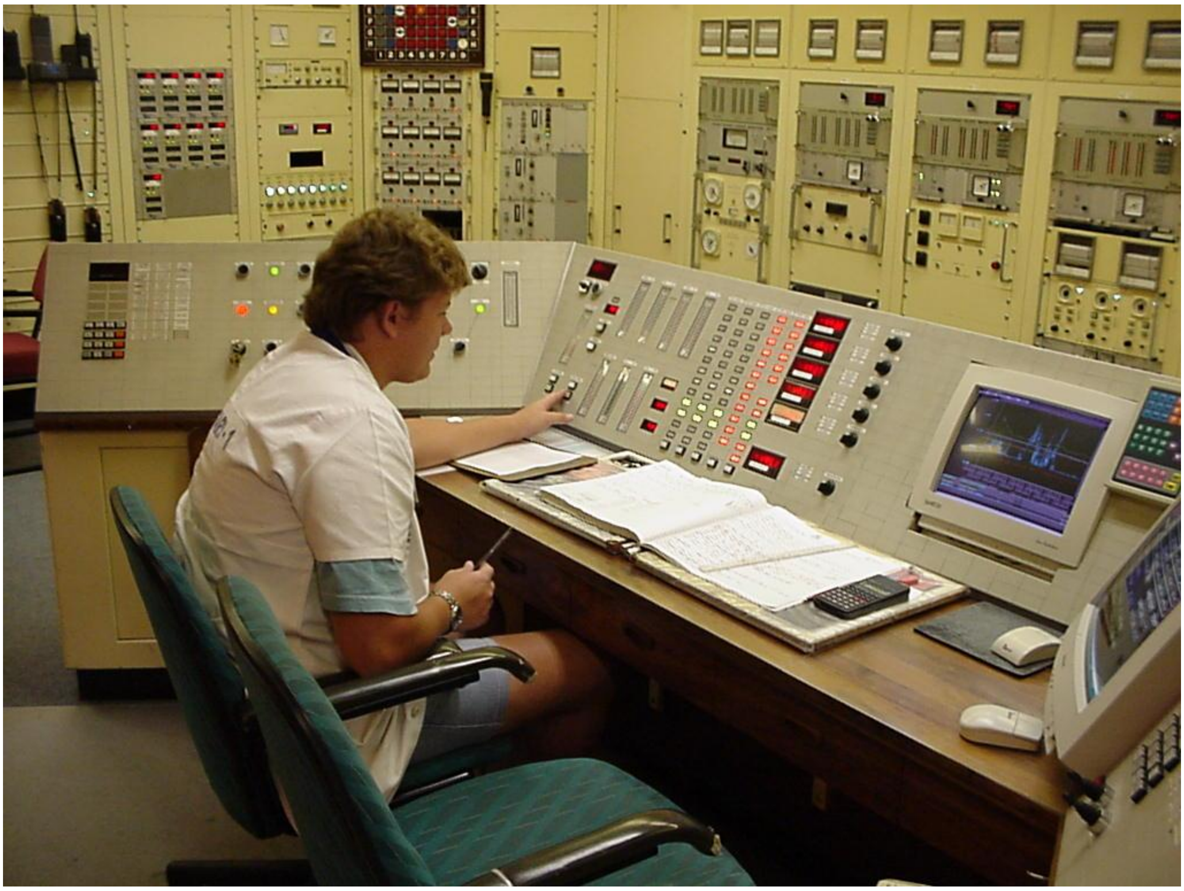

Figure 5a: Actual control room panels.

Figure 5b: Actual control room panels.

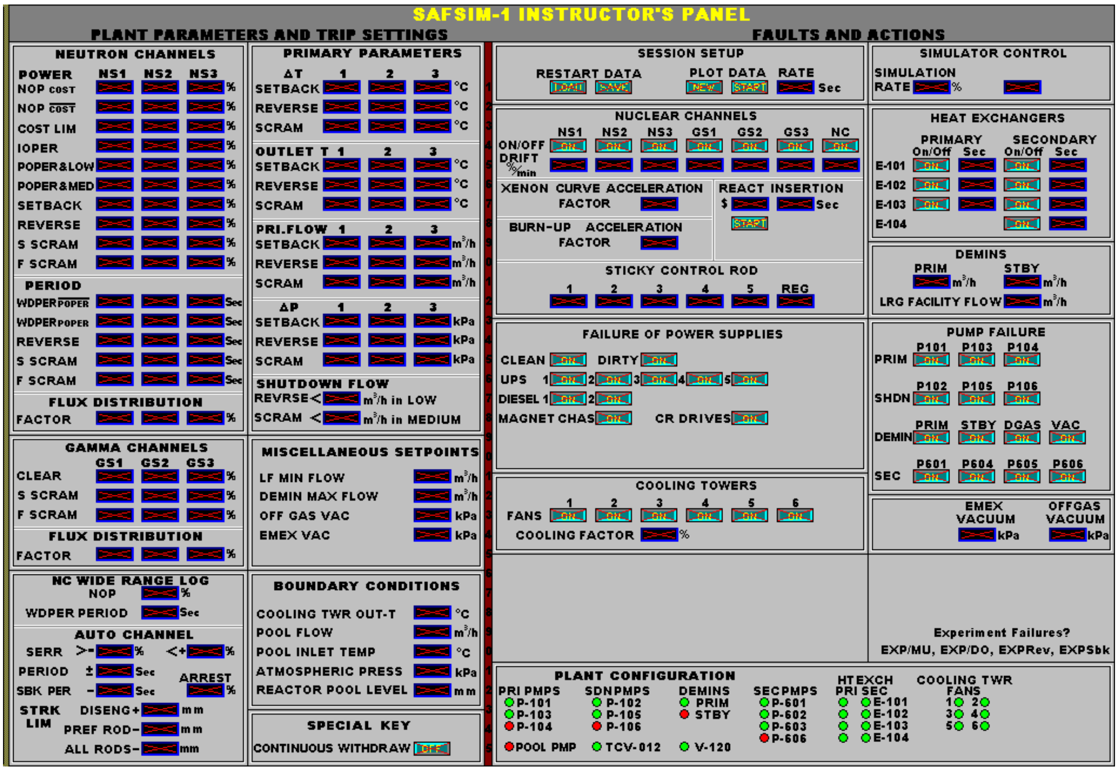

Figure 6: SAFSIM's Instructor's panel display.

4.0 References

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