CLASSROOM SIMULATORS

USER FRIENDLY EDUCATION WITH NUCLEAR REACTOR SIMULATORS

BY AURORA BADULESCU AND ROBERT LYON

Computer-based tools are becoming standard components of training programmes. In the nuclear industry, important strides have been taken in recent years to provide a wider range of education and training services based on the use of nuclear reactor simulators.

Through its programmes, the IAEA is sponsoring the development of nuclear reactor simulators that operate on personal computers and simulate responses of a number of reactor types to operating and accident conditions. The simulators provide training tools for university professors and engineers involved in teaching topics in nuclear energy and are also supplied directly to students, junior engineers, and senior engineers and scientists interested in broadening their understanding of the topic. The Agency arranges for the supply or development of such simulation programs and training material, sponsors training courses and workshops, and distributes documentation and computer programs.

Since 1997, ten IAEA workshops have been held in Vienna, Austria, and in Egypt, Saudi Arabia, Republic of Korea, and Italy. Altogether, training has been provided and simulators distributed to more than 181 participants from 42 countries.

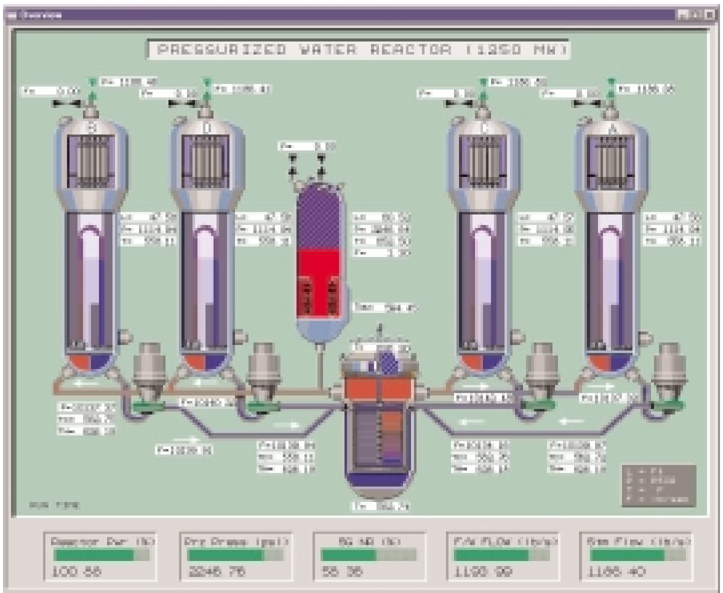
Simulator training has enabled participants to become fairly skilled in operating the simulation codes. It was clear that the combination of lectures on the physics and control of reactors together with the opportunity to test out the understanding on simulators was very effective in keeping up the interest of participants and of imparting knowledge about the operational characteristics of the various reactor systems. In a number of cases, the simulators are being or will be incorporated in national university syllabi or training courses.

This article describes the simulation programs sponsored by the IAEA. Four different programs are available covering different types of reactors, including pressurized-water reactors (PWRs), boiling-water reactors (BWRs), and heavy-water reactors (HWRs). The application of the simulation programs is limited to providing general response characteristic of selected types of power reactor systems and they are not intended to be used for plant-specific purposes such as design, safety evaluation, licensing or operator training.

Classroom-Based Advanced Reactor Demonstrators (CARDs). Known as CARDs for short, this is a set of nuclear power plant simulators developed by Canadian Aviation Electronics (CAE) Ltd. The set consists of PWR, BWR and HWR simulators and operates on a typical personal computer. The simulators are based on first principles and are modeled to the discrete component level. Control logic is based on the plant elementary diagrams, and dynamic models of plant hydraulic circuits are incorporated. The simulators are fully calibrated against both design and plant data.

The CARDs simulators make use of colour graphics to display data such as core flux, temperatures and voids, and to display the status of devices such as pumps and valves. Each of the three reactor models is referred to as a “CARD”. The CARDs package serves as a demonstrator and not a training simulator. Although the models used in the CARDs are subsets of CAE’s advanced full scope simulators, the package has been reduced to

Ms. Badulescu and Mr. Lyon are staff members in the IAEA Division of Nuclear Power, Department of Nuclear Energy.



only the necessary software required to demonstrate the general behavior of the plant as seen from the nuclear steam supply system, with all the boundaries to this system emulated to provide the overall dynamic response.

The demonstrators feature CAE's thermal-hydraulic model, and reactor model. The demonstrators consist of the complete neutronic and thermal-hydraulic model of the reactor and reactor coolant systems. The interfaces with the neighboring systems are emulated to provide a realistic feedback. The demonstrators employ a user-friendly, graphic-based man machine interface to manipulate the inputs, insert malfunctions, and display the behavior of the systems.

A graphic screen display of the reactor coolant circuit of the PWR consists of four heat transfer loops connected in parallel to the reactor vessel. Each loop contains a reactor coolant pump and a steam generator. The system includes a pressurizer, a pressurizer relief tank, interconnecting piping, valves and instrumentation necessary for operational control. *(See photo.)*

Advanced Reactor Simulator. This simulator was developed by Microsimulation Technologies in the USA and runs on a typical personal computer. It models a PWR, BWR and HWR in the 600-MWe range. For the PWR models, the simulator includes plants with vertical inverted U-bend steam generators of Western design, plants with horizontal steam generators as designed in the former Soviet Union, and a next-generation PWR with passive safety features.

The simulator operates in real or accelerated time and covers the nuclear steam supply system, containment, control systems, and safety systems. Malfunctions and parameters can be selected to model normal and abnormal design basis conditions relevant to each reactor type. Conditions outside the design basis can also be simulated.

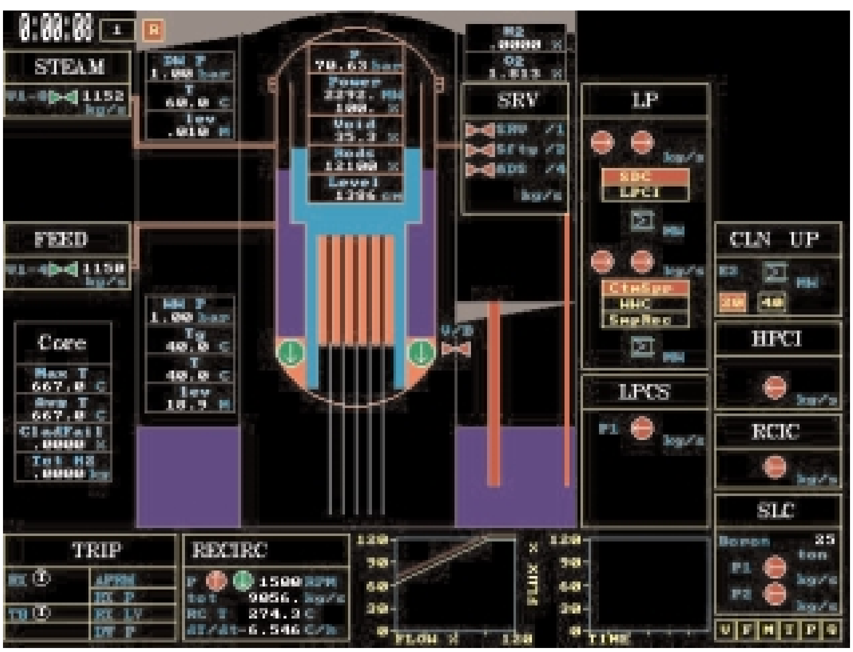


Photo: Top, computer display of the reactor coolant circuit of a pressurized-water reactor used in the Advanced Reactor Demonstrator for classroom training. Left, the computer screen for the boiling-water reactor Advanced Reactor Simulator, which runs on a typical personal computer.

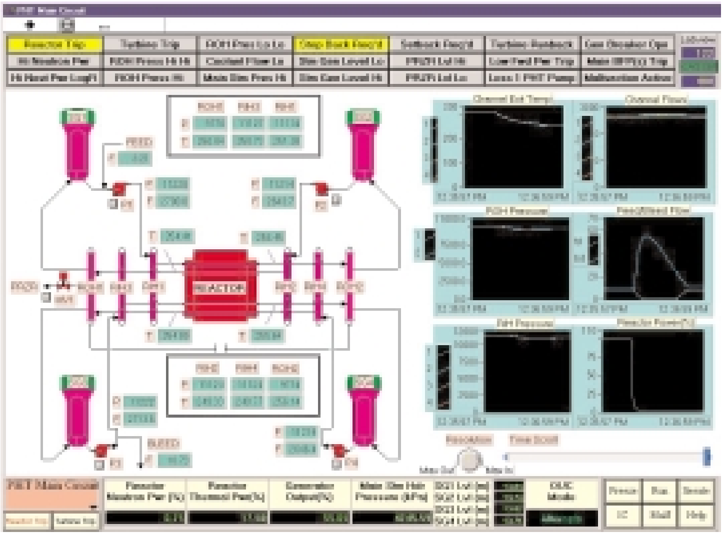


Photo: Computer display from the Candu-9 Compact Reactor Simulator.

The display represents the controllable system as small panels with the main components shown as icons. Components such as power-operated-relief-valves and safety valves of the pressurizer and the steam lines, pressurizer spray valve and heaters, main steam isolation valves, turbine bypass (steam dump) valves, feedwater valves and reactor coolant pumps are displayed. Their status is indicated by colour and can be overridden by the operator using the mouse to select objects for action (for example, push a button, turn on a pump). Keyboard access is only required for such actions as entering malfunction values, specifying a new initial condition and entering scale values for data trends. Control rod position and motion are displayed and pipe breaks are shown with flashing sprays at the break location with the leakage flow digitally displayed.

A typical run commences with selection from a set of initial conditions corresponding to various power, flow, and time-of-life conditions. During operation, the mimic dynamically displays the plant condition and the operator can initiate malfunctions that cover all categories analyzed in the plant's safety analysis report (and beyond for some cases). The severity, delay and ramp time of each malfunction is entered. The operator can trip the turbine or the reactor and can override the status of valves or pumps in the mimic, causing on/off status or partial failure at fractions of the full capacity. The operator can, for example, override the automatic initiation of emergency core cooling system pumps and take manual control. A set of malfunctions derived from the safety analysis report for each reactor has been prepared and can be selected, together with severity (for example, break size). Typical malfunctions include: loss of coolant; steam line break; loss of feedwater; and loss of flow.

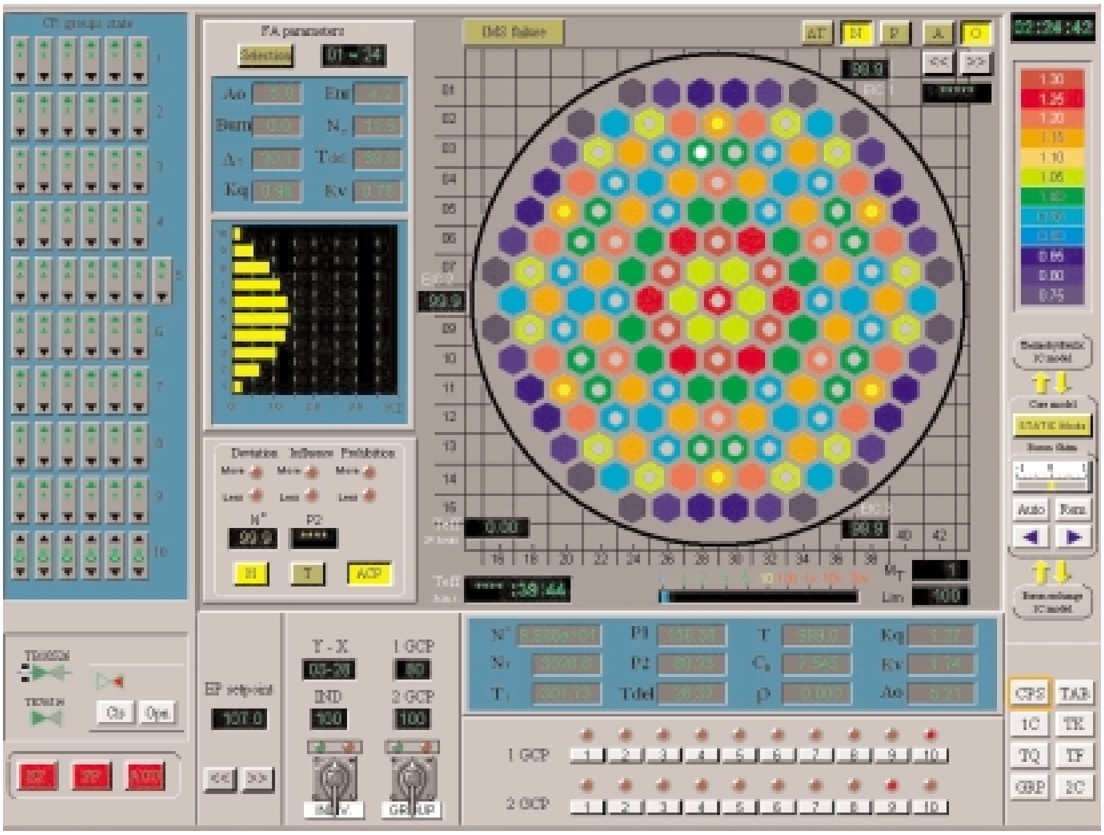
The status of the reactor protection system and safety feature actuation system is displayed. The reactor will trip automatically upon conditions exceeding any of the reactor protection system set points. The corresponding symbol will turn red and all control rods will be inserted.

Output variables can be viewed in "trend" graphs on the screen as the simulation progresses. Graphs can be printed at the end of the simulation. The operator can choose to have the calculated transient parameters written into output files for detailed post-simulation analysis.

CANDU-9 Compact Reactor Simulator. This simulator, developed by Cassiopeia Technologies Inc., has 16 interactive display screens, showing overall plant systems, subsystems and control and safety systems. Each screen indicates, at the top and bottom of the display, 21 plant alarms and annunciations, simulator status, major plant events and parameters. The interaction between the user and the simulator is via a combination of monitor, mouse and display. Control panel instrumentation and control devices, such as push-button and hand-switches, are shown as stylised pictures, and are operated via special pop-up menus and dialog boxes in response to user inputs.

The simulator uses an object-oriented approach, and it responds to the operating conditions normally encountered in power plant operation, and to many malfunction conditions.

When the plant's overview is displayed, the heat transport main loop, pressure and inventory control systems are



shown as a single loop. Four steam generators are individually modelled. Reactivity control has a separate screen that shows the limit control diagrams and the status of the three reactivity control devices that are under the control of the reactor regulating system.

There is fully dynamic interaction between all simulated systems, the unit power regulator, unit annunciation systems, and computer control of all major system functions.

Compact Computer Simulator of VVER-1000. This simulator, developed by the Reactor Department of the Moscow State Engineering Physics Institute, provides three main work regimes: preparation (configuration) of a simulation session, running of models, and visualization and analysis of simulation results. The simulator includes eight screens showing the major technological systems, and models normal operation and abnormal situations concerning the response of the safety systems and faults of equipment.

The simulator is based on an integrated software package providing a wide set of functions covering development and operation of simulation complexes. The system provides the following possibilities: ordered form of work file storage and presentation; easy running of other components; simple method for configuring simulation sessions; and storing of destination files.

Fuel is modeled in three dimensions and a homogenous thermal hydraulics model is provided for core coolant. The neutron kinetics model can run 30,000 times faster than real time, which is very useful for investigating fuel burnup and xenon processes.

Also featured is a model of a boron regulator, which is useful to manually regulate boron concentration for a long period of time. It is also possible in the simulator to disconnect the plant regulation system, and operate in the manual mode.

A monitoring process is provided to evaluate the trainee's performance using the simulator. ❑

Photo: Computer display of the VVER-1000 compact computer simulator.