Simulator at Surry nuclear plant in Virginia. (Credit: INPO)

Simulation technology in operator training

Full-scope, plant-specific simulators are part of the new reality

by Thomas Perkins

In the late 1960s and early 1970s, the nuclear power industry in the United States made its commitment to simulator training for nuclear power plant operators. During this period, all four US nuclear steam supply system vendors opened their own training centres, each including its own full-scope nuclear plant simulator. Operators from utilities around the world attended generic courses on nuclear power plant operations at these centres. Transition training to the specifics of individual plants was accomplished once operators had returned to their respective plant sites.

By the end of 1978, the use of simulators in the training of nuclear power plant operators had gained worldwide acceptance. Training centres existed in Canada, France, Federal Republic of Germany, Japan, Spain, Sweden, the United Kingdom, as well as in Taiwan, China. The American National Standard for Nuclear Power Plant Simulators for Use in Operator Training, first approved in 1977, set minimum requirements for simulators used to train and to qualify nuclear power plant operators. Operator training focused mainly on normal operating procedures and a review of improbable, catastrophic accident scenarios. The nuclear industry assured the public that safety measures built into nuclear reactors and control rooms ensured that "a serious accident could not happen".

On 28 March 1979, a major accident occurred at Three Mile Island (TMI) Unit 2 in Middletown, Pennsylvania. The TMI accident resulted in a critical assessment of the preparedness of operations staff to respond to the accident. The post-accident findings of the Kemeny Commission and other recommendations concerning simulators have had a significant impact on the nuclear industry's approach to operator training.

It is commonly believed that the incident at TMI would not have occurred had the operators been properly trained, but simulator training alone would not have averted it. Simply speaking, existing simulators were not programmed to handle a reactor transient where much of the primary coolant was lost. The TMI accident has prompted a complete re-evaluation of the nuclear industry's operator training programmes.

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Recognition of the complexity of the processes, the demands placed on operators, and the importance of training are resulting in comprehensive training programmes administered by industry and government agencies. Traditional apprentice training can no longer be considered as a viable approach to nuclear plant operator training. The old approach of "train the hand, not the mind" has given way to an integrated, systematic, performance-based approach to training nuclear plant personnel.

The complexity of today's plants requires that a simulator be the principle tool a qualified instructor uses to teach and to assess an operator's ability to perform under normal and abnormal plant conditions. However, acquisition of a full-scope, plant-specific simulator is just one component in an effective training programme. Today's integrated training programmes include extensive classroom study in the theory and principles of operations coupled with hands-on simulator training. Normal operations, the more probable accident events, and the man-machine interface are emphasized.

Post-TMI simulation

A full-scope, plant-specific simulator consists of a replica of the plant control boards, operating consoles, and instructor's station all activated by a large digital computer system. Computer programs are developed that are mathematical representations of the physical phenomena of the plant systems and transfer functions of the control system.

This description is as valid today as it was in early 1979. The major difference between today's simulators and those delivered in the late 1970s is the fidelity and accuracy of simulation – fidelity as applied to the evolution of normal and abnormal plant events, and accuracy regarding tolerance requirements for steady-state and transient conditions. (Fidelity is the degree of similarity with the reference plant.)

Some salient features of today's full-scope, plant-specific simulator are described in the following sections.

The control room

A full-scope simulator typically includes a faithful and complete replica of all of the equipment in the main control room of the plant. The completeness of the reproduction is dependent on the individual customer specification. Some utilities specify an exact replica including all back panels, lighting (including the dimming effects associated with starting large motors), flooring, and even sound effects (turbine noise, steam dumps, etc.) keyed to the opening of control room doors. Others require only the reproduction of the front panels and, in some cases, not all front panels are included.

A typical simulator in the late 1970s had an input/output (I/O) count – an indication of the amount of simulated control room instrumentation – of between 6000 and 8000. Today it is not unusual to have an I/O count of between 16 000 and 20 000. In addition to the consoles of the main control room, the remote shutdown panel is also replicated and located in a separate room.

Other equipment in the plant's main control room, such as the plant process computer's integrated control systems and the safety parameter display systems, are also included in the scope of simulation. With more and more emphasis being placed on elaborate display systems, it is becoming exceedingly important to familiarize the operators with the simultaneous display of information on CRTs and on conventional instrumentation.

Through this extensive use of display systems, the accuracy and fidelity of models can now be observed to a degree never before available to the trainee. These new demands for accuracy and fidelity are extending the delivery time and consequently significantly increasing the cost of today's simulators.

Studies currently are under way to determine what is realistically required to provide effective operator training. Are the systems necessary for plant auxiliaries operation and surveillance on a long-term basis actually required for simulator training? What are the requirements for training the plant operator and what other plant personnel will be trained on the simulator? These questions must be addressed by each organization planning to procure a full-scope, plant-specific simulator.

The question of extent of simulation, and fidelity and accuracy, must be assessed in determining the most cost-effective solution to providing efficient operator training. In making this decision it is important not to forget the primary purpose of a training simulator: that is, to provide sufficient information to the trainee to allow him to verify the normal or abnormal operation of the plant, and to allow the trainee to interact with and to observe the response of the process to his control actions or inaction.

Instructor's station

With increased training simulator complexity, the role of instructor as manager of the training exercise is becoming more and more demanding. The instructor must be able to easily and rapidly manage malfunction insertion, auxiliary operator functions, establish trending displays, and above all, monitor the trainee's performance. To meet these objectives, the typical instructor's station utilizes large-screen, high-resolution, colour-graphic displays coupled with a well-developed "instructor friendly" design approach. This allows the instructor to rapidly accomplish his major task of establishing the training scenario.

The use of time-saving, programmable function keys, cursor-controlled function selection, and micro-driven input techniques allows the instructor to spend more time accomplishing his primary objective of teaching.

Typically, an instructor's station includes the following features:

- Initialization to a predetermined status
- Freeze all calculations
- Malfunction insertion (instantaneous or logical)
- Auxiliary operator functions
- Backtrack to an earlier point in the training exercise
- Monitor trainee performance
- Override/fail control room instrumentation
- Insert spurious alarms
- Fast and slow time
- Computer-aided exercise programs
- Control environmental conditions and other external parameters.

In addition to the instructor's station console, a hand-held, remote-control device is provided for use by the instructor in over-the-shoulder training. This device allows the instructor to control the training exercise while closely observing the trainee in the control room.

Primary system models

Simulator specifications issued since TMI have clearly stated the requirement to address two-phase-flow and associated heat-transfer processes. All major simulator manufacturers have embarked on development programmes to accurately address these requirements, and today this new breed of advanced simulators is available to the nuclear plant operator training industry.

For example, Link's Real Time Advanced Core and Thermohydraulic Code (RETACT) is used as the nucleus of Link's advanced power plant simulators. It provides the predictive capability of a thermohydraulic code, in addition to the entire operational ability of a training simulator. A separate display system, located adjacent to the instructor's station, also provides dynamic information on all parameters needed for in-depth diagnostics of the plant's capability to transfer energy from the reactor coolant system to the turbine or other energy sinks. The model is developed with physical laws and with basic constitutive equations that are at the same level as the best safety analysis codes. The results can be said to be best-estimate results. The predictive nature of these advanced models allows operator training to a depth and realism never before available.

Major simulator manufacturers currently are demonstrating their advanced models to potential customers, and in fact, several simulators using them are already under design in Europe and the United States.

Design data base and future modifications

The fidelity in design of the plant systems models is dependent directly on the quality of the design data base. The collection and maintenance of this data base is a time-consuming task for both the utility and simulator manufacturer. This design base must be well defined, and the simulator owner must maintain an accurate and current data base on the reference plant. As changes are made to the reference plant, each change must be evaluated and appropriate modifications incorporated into the simulator. In turn, the simulator design data base must be updated to reflect the simulator's current status. Thus, a computerized configuration management system is now a requirement for most simulators being manufactured today.

The simulator owner and manufacturer must work closely during all phases of the project to collect and correlate all applicable data available on the reference plant. When possible, actual plant operations data, including accident and emergency transients, are utilized in the initial design. If the simulator is being designed ahead of or in parallel with the reference plant, then the simulator must be fine-tuned after the plant comes on line. This fine-tuning is normally accomplished either by the simulator owner's software maintenance personnel or under a separate agreement with the simulator manufacturer.

This fine-tuning effort and future modification of the simulation mathematical models must be easily facilitated, in terms of understanding the models and modifying them without affecting the rest of the software. To accomplish this, the math models for all the various systems must be organized in a modular form, with a minimum of interfacing between models. A "top-down" design approach to systems modelling – where one control module calls one or more code segments that in turn call various components and sub-routines – provides for this ease of future modification.

Due to the modular nature of today's design and the elaborate software maintenance tools delivered with the simulator, most simulator owners are able to implement most changes without the assistance of the original manufacturer.

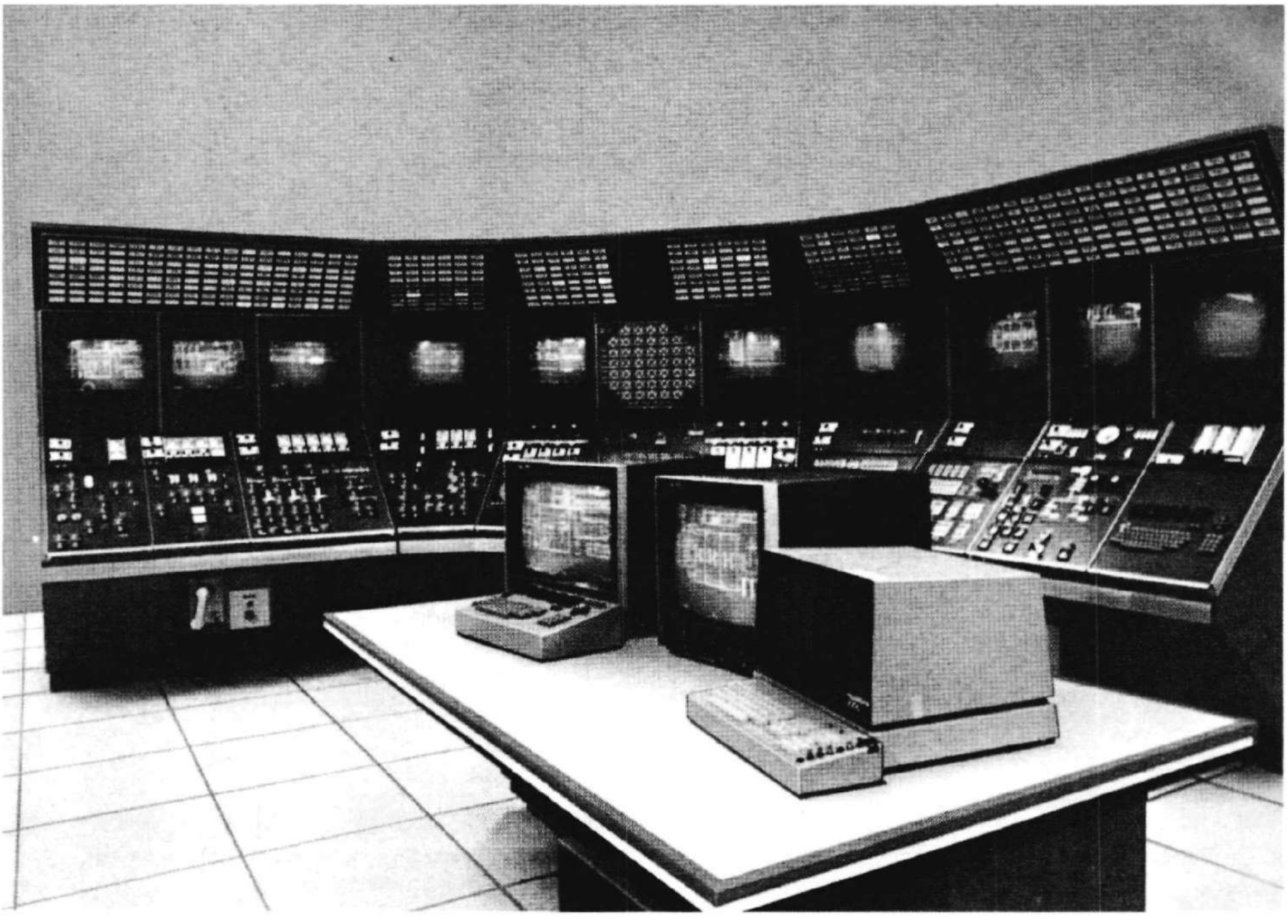
Computer system

"Computer system" refers to all necessary hardware and software for the implementation and proper operation of the simulator. This includes the I/O interfaces with the control room instrumentation.

Many simulator manufacturers are currently proposing Gould Computer Systems Division 32 Series computers. A computer complex must have sufficient computing speed, memory capacity, and programming flexibility to achieve the performance levels demanded of the simulator.

Typically, the system must be capable of performing the following:

- Control the simulation process
- Realistically reflect real-time responses of control manipulations by the operator-trainee
- Maintain control of all computer peripheral devices and their intended functions
- Provide sufficient digital word lengths to reflect specified accuracies



Plant-specific simulators are replicas of a particular control room. Shown are the systems for the Susquehanna nuclear plant in the USA (top) and for the Ontario Hydro Bruce "B" CANDU power plant in Canada. (Credit top photo: Link SSD; bottom: CAE Electronics Ltd.)

From airplanes to power plants and beyond

Standing behind the development of today's sophisticated simulators for training nuclear-plant operators is the experience gained in more than 50 years of simulation technology in the aerospace industry.

Within the past half century, flight simulation technology has moved from mechanical pilot trainers to complex computerized systems imitating outer space missions. Before the US Space Shuttle Columbia conducted its first operational mission in late 1982, for example, both the crew and support personnel had used simulation technology to rehearse their respective roles from launch to landing.

Just as their own development over the past 25 years evolved from past experience, modern nuclear-plant simulators now are leading the way for many other types of operator training devices in the electric power and other industries.

Fossil-fuelled power plants have been using sophisticated full-scope simulators for operator training since 1977. Today these are located in various countries, including Australia, China, the Federal Republic of Germany, India, Indonesia, Republic of Korea, Saudi Arabia, South Africa, and the United States. Other types of simulators are located in many other countries.

Process industries are the most recent ones to utilize simulation for operator training. The use of simulation technology in this industry, in fact, has gone beyond the realm of plant operator training. Today, real-time simulation technology is proving to be a cost-effective tool in the design of highly complex process plants. For example, the fidelity of simulation is providing a better understanding, allowing the plant owner to make plant design modifications and process-control changes before or in parallel with the actual plant construction and start-up phase. In several cases, the savings in equipment cost and start-up time have more than recovered the cost of the simulator.

Experience gained in nuclear-plant simulation has helped develop simulation systems for other industries, such as the one shown here for a gas processing plant. (Credit: Link Simulation Systems Division)

- Provide sufficient input/output transfer rates and math model iteration rates so the simulated plant responses observable in the control room are not readily discernible from those in the real plant
- Support software system maintenance and program modifications activity through appropriate language processors and support programme
- Support background processing functions concurrent with simulator operations, subject only to resource and time availability
- Provide sufficient spare time and memory (or expansion capability) to accommodate future modification.

A typical Gould computer complex would include, as a minimum, a dual 32/97 Series computer; a line printer; CRT display terminals; 300-MB disc drives; 75-IPS magnetic tape units; and a 1000-CPM card reader.

Developments in the computer field are occurring so rapidly that, quite often, by the time the simulator is delivered, its computer is at least one generation behind the current state-of-the-art. Therefore, the portability of the software has become an extremely important part of the simulator's design. Several areas now receiving additional attention in the design of a portable system are the utilization of the computer vendor's operating software without modification, programming totally in a high-level language, and the use of structured design and programming.

Malfunctions

Malfunctions are defined as a failure or degradation in performance of plant components and may be grouped into two types: generic malfunctions, and system-specific malfunctions. Generic malfunctions cover most plant components such as pumps, valves, heat exchangers, regulators, etc., while system-specific malfunctions include fuel leakage, condenser tube leak, pipe breaks, etc.

Trends in nuclear simulation

In the nuclear industry, the first two nuclear plant simulators were built in 1957 almost in parallel with each other. The first to be completed was in the United Kingdom for training operators for the Calder Hall magnox station. The second was for the nuclear merchant ship *Savannah*. Both of these simulators could be referred to as a replica simulator, since each faithfully duplicated the control room of the actual plant. In fact, the *Savannah* simulator was capable of being used to perform engineering studies of the ship's propulsion system.

Today's types range from basic-principles trainers to full-scope, plant-specific simulators, providing a full range of training devices for students with no practical experience, as well as those with many years of actual operations experience.

Basic-principles trainers are intended to provide a fundamental understanding of the cause and effect relationship between systems of a nuclear power plant. It is becoming a well-accepted fact that initial training of operators and support staff can best be accomplished on this type of conceptual simulator. Learning the concepts behind the operation of a nuclear plant is easier for the inexperienced trainee when he is not overwhelmed by the details of a replica control room. Once the basic principles have been learned and fundamental operating skills have been acquired, the operator can confidently move up to training on a replica simulator.

The full-scope, plant-specific simulator provides a replica of the reference plant control room. The fidelity of simulation of plant systems is such that an experienced operator should not be able to detect any difference in operation of the simulator or the actual plant. The accuracy of the simulation is well defined, with critical parameters and associated tolerances clearly specified.

Between these two types of simulators lies an entire spectrum of training devices for nuclear plant operators and support staff.

Simulators in use

According to IAEA reports, conceptual simulation based on small mini-computers that do not represent every system detail are becoming a new training tool. About one dozen of these simulators are now in use.

More clearly, there is an increasing trend toward plant-specific simulators. About 100 full-scope nuclear power plant simulators for training are now in use or under construction worldwide, the IAEA estimates.

In Czechoslovakia, the training centre of the Nuclear Power Research Institute uses a domestically produced VVER-440 simulator. It is the most advanced simulator in Member States of the Council for Mutual Economic Assistance (CMEA) and allows simulation of normal operations, anticipated occurrences, and accident conditions.

One of the world's most complex nuclear-plant simulators has been put into operation at the training centre for the Hunterston-B advanced gas-cooled reactors in the United Kingdom. It uses 52 microcomputers in a parallel processing mode, with a combined directly accessible memory of over 10 megabytes.

Work also has been completed on a French multi-purpose functional analysis simulator that can simulate normal operations and complex accident scenarios in real time. It can be used for system design and development of operating procedures, but its strongest point is accident simulation. The effects of an accident on the whole plant are shown along with several possible courses of action.

Although simulators have traditionally been used for training personnel and developing operating procedures, they also can be a valuable research tool. This has been demonstrated in the validation of an advanced safety parameter display system for the Loviisa nuclear plant in Finland.

The American National Standard for Nuclear Power Plant Simulators for Use in Operator Training requires a minimum of 75 malfunctions to demonstrate inherent plant responses and the functioning of automatic plant controls. In addition, the standard also requires that the fidelity of simulation must allow the operator to take action to recover the plant or mitigate incident consequences and return the plant to a reasonable operating condition.

Today's simulators far exceed these minimum requirements, having the capability to simulate the failure of almost every component in the plant, resulting in many hundreds of malfunctions. These generic and system-specific malfunctions, coupled with the instructor's capability to fail each item of control room equipment, leads to a virtual cornucopia of malfunction scenarios.

A joint venture

To summarize, the typical full-scope, plant-specific simulator being manufactured today is truly a joint venture between owners and suppliers. From initial data collection efforts through final verification testing, a close working relationship is established and strong team spirit is developed. The ever increasing complexity of the simulator demands this close relationship, and the quality of the final product benefits heavily from this co-operation.

We must not lose sight of what the real purpose of a training simulator is and how the various training devices — from part-task trainers to full-scope, plant-specific simulators — can best be utilized in an integrated training programme.