



# **The Role of Microsimulators in Training**

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## INTRODUCTION

At the end of 1985 Ontario Hydro had fourteen nuclear units of the CANDU type in-service with a total capacity of 8284 MWe. Seven more CANDU units are under construction, amounting to an additional 5700 MWe generating capacity. The last of the currently committed units is scheduled to be operational in 1992. At that time approximately 70% of the electric power generated in Ontario is expected to come from CANDU units.

Since the inception of the commercial nuclear-electric program in the late 1950's, Ontario Hydro had to train most of the staff required to operate and maintain the CANDU generating stations. At the end of 1985 the staff working in nuclear operations numbered 5674. The current training load consists of 300 newly hired trainees, the on-going development of existing staff, and significant levels of upgrading and refresher training.

The training programs designed and conducted by Ontario Hydro follow the principles of systematic training, including analysis, design, development, implementation and evaluation. The goal of the nuclear training program is staff capable of performing their jobs so as to meet the station operating objectives in the areas of public and worker safety, reliability, environmental protection and cost.

In 1972 Ontario Hydro recognised the need for a full-scope replica simulator in order to provide the desired level of training in control room operations for unit first operators and shift supervisors. The simulator for Pickering NGS-A was placed into service in 1976. Although the simulator satisfied its training mission for the staff of Pickering NGS-A, it became evident that a simulator dedicated to Bruce NGS-A was required to train the staff of that station. Early in 1979, prior to the accident at Three Mile Island, Ontario Hydro adopted a corporate policy which required a replica full-scope simulator for each generating station that had a control room man-machine interface significantly different from existing units. This policy resulted in the acquisition of five simulators, as shown in Table 1.

TABLE 1  
 Simulator Acquisition Program.

| <u>Reference Plant</u> | <u>Net Capacity MWe</u> | <u>First Unit In-service</u> | <u>Simulator In-service</u> |
|------------------------|-------------------------|------------------------------|-----------------------------|
| Pickering A            | 4 x 515                 | July 1971                    | Nov 1976                    |
| Bruce A                | 4 x 754                 | Sept 1977                    | Apr 1983                    |
| Pickering B            | 4 x 516                 | May 1983                     | July 1984                   |
| Bruce B                | 4 x 830                 | Sept 1984                    | May 1986                    |
| Darlington             | 4 x 881                 | May 1988                     | Jan 1988                    |

In addition to the above full-scope replica simulators, other training aids that utilised computer simulation were also developed to support the training program. In each case the need arose when hands-on training was desired, but the actual equipment was not available for training purposes for reasons of safety or economy, and a computer simulation was judged to be a cost-effective alternative to configuring a physical model of the equipment or system.

#### Microsimulators

The term "Microsimulator" (or microsimulation) was coined to describe the micro-processor based interactive simulation of dynamic system behaviour, as developed in the Simulator Services Department of Ontario Hydro. It has the following three main features which distinguishes it from other micro-processor or personal computer based simulations:

- a. the mathematical model is based on the physical principles that characterise the processes being simulated,
- b. the system and its control instrumentation is displayed in a stylised form on a colorgraphics monitor,
- c. the trainee interacts with the simulated system via a touch-sensitive transparent screen mounted in front of the monitor.

The equipment presently in use for our microsimulators is the Intelligent Systems Corporation ISC 8063 graphics terminal. The 19 inch monitor uses character and pixel generation to produce the graphics displays, has eight colors and moderate resolution (480 x 384). The micro-processor is an INTEL 8080 with 64K RAM. The CP/M operating system allows programming in both FORTRAN and ASSEMBLER. FORTRAN is used for the modelling of processes, equipment and control logic, and ASSEMBLER for all inputs and outputs, including graphics subroutines. Dual 8 inch floppy disk drives

of 960K capacity are used for mass storage. The touch-sensitive screen is an ELOGRAPHICS model E271-10.

The above equipment, with some upgrades, has been in use since 1979. Apart from meeting the requirements as a training tool, it was also chosen for the Safety Systems Monitoring Computers at the Bruce stations, and as the display units for the control system of the Tritium Removal Facility at Darlington. Although more sophisticated equipment is available to-day, there have been significant advantages in working with the same terminal for several years, and having it compatible with station equipment. It is recognised that as applications for more complex simulations arise, computers and monitors with higher capabilities will have to be used.

#### Performance-Based Training

The terminal objective of training is to have staff able to meet the on-the-job performance requirements of the designated positions. In order to implement such a training program it is necessary to be able to identify the knowledge and skill components of each job, and to be able to impart and evaluate these in a controlled environment. Knowledge can be transferred in formal lectures or self-study, and assessed by written or oral examinations. Skills can be taught and evaluated on-the-job or in suitably equipped shops and laboratories.

The essential steps in a systematic approach to training have been described by INPO (Institute for Nuclear Power Operations) as follows:

- a. job and task analysis, which establishes the capability requirements for the job and defines what the employee will need to know and be able to do as a result of training, in terms of on-the-job performance;
- b. training design, including the establishment of job performance measures, learning objectives, teaching and testing methods;
- c. development of lesson plans and supporting material for both knowledge and skill objectives;
- d. implementation of the training plans, including the conduct of training, in-training evaluation in terms of the knowledge and skill objectives, and documenting the results;
- e. evaluation in terms of on-the-job performance, as measured by safety, maintenance and operational indicators, as well as feedback from the trained employees and their supervisors;

Microsimulations have two main areas of application in the above training methodology: the teaching of knowledge required for the understanding of complex, dynamic system behaviour, and for the performance testing of

skills which are not readily verified on-the-job or in shops equipped with conventional equipment.

Knowledge applications include the orientation of commissioning staff (many of whom are authorized to operate an existing station) to the systems of a plant under construction. The microsimulator supplements the design information, and provides an opportunity to learn the design intent of the new station's systems. Other examples are in the area of control systems, including relay logic, analog control, digital computer control and programable controllers.

As a tool for performance testing, we have primarily used the microsimulators in cases when a full-scope simulator was not available. In these applications the microsimulator is used to verify the trainee's ability to operate the particular system according to the approved operating procedures.

A number of applications in both knowledge and skill areas is described below, as well as our expectations for the future uses of this training tool.

## Control System Theory and Equipment Principles

### Analog Control

We first developed microsimulations in support of the instrumentation and control training program. The problem areas addressed were the knowledge required to understand the functions of analog controllers for a variety of process systems, and the development and verification of skills to tune and trouble-shoot controllers of various complexity.

Figure 1 shows two CRT displays for a system that controls the level in a tank. The upper display shows a schematic diagram of the system, which includes a pump, two control valves, level and flow transmitters and controllers. The lower display shows the control panel instrumentation for this system. (Please note that on the print-out black is shown wherever white would appear on the monitor and vice versa). The control scheme is cascade, wherein the tank level is maintained at the set-point by a combination of level and flow measurements and flow control. The trainee would also have the opportunity to study the responses of single element (level only) and three element control (level, inflow and outflow) by selecting the appropriate system configuration.

The schematic display is used to ensure that the trainee understands the operation of each component in the system and to be able to visualize the system's response. It is also a convenient means to display the range and output of each transmitter, and the gains of each controller. Malfunctions are also introduced from the schematic display. These include valves failing open or closed, and various transmitter and controller faults. Valve characteristics and responses (linear, equal percentage, fast acting) can be altered, along with tank capacitance,

supply flow and pump head. From the front-of-panel view the pump may be turned on or off, controller set-points changed and valve positions altered. All of the above operations can be performed via the touch sensitive screen.

The front-of-panel display is used to verify the trainee's skills in operating the system remotely, and troubleshooting controller and transmitter faults using the panel instruments. The specific training objectives would be somewhat different for operators and for control technicians.

#### Programable Controllers

A more recent example of using microsimulation to train control equipment operating and troubleshooting skills arose with the large scale use of programable controllers at Darlington NGS. The equipment, designated as OH180, is based on an INTEL 8085 and was designed by Ontario Hydro. More than 1000 of these programable controllers will be used at Darlington, replacing most of the relay logic used on previous stations. The lack of sufficient spare controllers, the risk of damaging the equipment and the need to introduce fault conditions, led to the development of a microsimulation module to support the training delivery program.

Figure 2 shows the stylised representation of the front-of-panel instruments of the programable controller. It consists of four subsystems: INPUT, OUTPUT, CPU and POWER SUPPLY. The small diamonds represent LED status indicators, corresponding to 24 digital inputs, 16 digital outputs and 8 CPU malfunction conditions. By touching the I/O CARD SELECT switch, either the input or output card can be chosen. The position of the GROUP SELECT switch determines which set of signals can be tested. The FUNCTION switch is used to choose which of eight tests will be performed on the selected bank of I/O points, such as ground fault, input-output discrepancy, blown fuse, etc. All of the above functions of the real equipment can be learned and practised using the microsimulation.

A major feature of the OH180 is the quick identification of ground faults, as well as failures within the programable controller itself. A variety of faults are available for the instructor and the trainee to demonstrate and practise the diagnostic procedures for the detection of faults. (A sample menu is shown as part of Figure 2). At the completion of the course the trainee must satisfy the instructor that the prescribed level of proficiency under standard and fault conditions has been achieved. The primary target population for this training is the control technician family, but operators and engineering staff will also have to attain proficiency in the use of these units.

## Nuclear Operator Training

The majority of the microsimulations developed by Ontario Hydro to-date have been for the the training of nuclear generating station unit first operators and shift supervisors. As described in this section, microsimulations have been developed for a wide variety of station systems, from the reactor to the electrical output system: for a single unit station that had been in operation for over 15 years to a multi-unit station two years away from first critical. The examples to follow will illustrate both the variety of systems that can be simulated and the areas of application for microsimulators.

### No full-scope simulator

The Douglas Point Nuclear Generating Station went into service in 1967 and remained in operation until 1984. It had a capacity of 208MWe, and achieved a lifetime capacity factor of 53%. Douglas Point NGS is owned by AECL and operated by Ontario Hydro. Because of its modest size and being the prototype for the commercial CANDU units, a full-scope simulator was not acquired for Douglas Point NGS.

An operator performance problem was identified in 1980 with the emergency transfer system. Lack of detailed understanding of the complex logic system coupled with no opportunities to observe and practise its operation were identified as the causes of the problem.

A replica of the relevant portion of the electrical distribution system control panel was built during the early years of the station, but it could only be used when the unit was shut down, and it was not kept up-to-date with changes made in the control room. The cost of updating the replica panel and its usefulness for training were compared to developing a microsimulation. It was determined that the microsimulation would have greater scope, availability and flexibility as a training tool than the modified replica panel, and it could be implemented at a lower cost.

The scope of the simulation included the electrical output system and the station electrical distribution system. The latter consists of four classes of power and three different voltage levels. The system is shown in schematic form on Figure 3. This diagram is a copy of what the trainee sees on the monitor. Although it is not a replica of the control panel instrumentation, the trainees had no difficulties in identifying the appropriate panel devices and performing the designated standard, nonstandard and emergency operations.

Referring to the diagram, the simulation includes the following systems: generator, electrical output, class IV power which supplies all normal station loads, class III power with standby diesel generators to supply back-up power to essential loads in case of class IV power failure, class II power which supplies loads that can be interrupted only momentarily, and class I power supplied continuously from batteries.

The electrical output system includes the main transformer (50T1), two 230kV transmission lines and relevant breakers. Class IV power is distributed to the station loads via four buses. Two of these are normally supplied from the generator service transformer (50SS1) and two from the system service transformer (50RSS1). The automatic transfer scheme determines when this arrangement needs to be altered. For example, if the main generator trips, the buses supplied from the generator service transformer (BU C and BU E) will be automatically transferred to the system service transformer by opening CB1 and CB5, and closing CB2 and CB6.

The 600V Class III buses (BU L and BU M) are normally fed from Class IV via transformers T1 and T2. Class III in turn feeds the Class II buses (BU N and BU P). The Class I buses and the batteries are normally supplied from Class II via motor-generator sets MG1 and MG2.

Back-up sources of power can be supplied by two standby diesel generators (SG1 and SG3) and the batteries. Several alternate means of supplying each bus have also been designed into the system, such as the ability to power all the Class IV buses from either transformer, supplying a Class III bus via the Class IV transfer bus (BU K) and supplying Class I power from Class III via rectifier R1.

The trainee can use the microsimulator to perform the majority of the standard, nonstandard and emergency procedures that would be done at the real control panel. Transmission lines, buses, transformers can be placed into or taken out of service. The main and standby generators, as well as the motor-generator sets may be operated as required. Fault conditions on all of the above equipment, on the circuit breakers and in the logic circuit may be introduced, and overcome by following the approved operating procedures. The various automatic transfer schemes which come into operation when abnormal conditions are detected can be observed and augmented as necessary. In each case the trainee interacts with the simulation by touching the symbol for the appropriate device on the display.

To appreciate the operator knowledge and skill required to monitor and correct the actions of the emergency transfer system, consider the automatic actions which are designed to take place on a total loss of Class IV power. Normally neither standby generator would be operating, so on a loss of Class IV power Class III power would also be lost, as well as, momentarily, Class II. As soon as the loss of Class II power was sensed, the MG sets would reverse their operation, drawing on the batteries to supply the Class II buses. In order to prevent the propagation of a possible fault from Class IV or Class III, and to minimize the load on the batteries, breakers CB6 and CB7 open, separating the Class II and Class III systems.

The emergency transfer system will automatically start the standby generators and will open all supply and feeder breakers from the Class III buses while the standby generators run up. When the standby

generators reach their operating speed, the emergency transfer system logic will close the standby generator supply breakers (5231-CB11 and CB51) to the isolated bus to restore the 600 V supply. The Class III loads are picked up in a prioritized sequence, followed by the Class II supply breakers across which the Class III and Class II buses must be synchronized. Once the emergency transfer system has closed breakers 5231-CB6 and CB7, the MG sets will revert to the DC generation mode, recharging the batteries. Having restored Class III power, the operator can prepare to shut the unit down, or, if recovery of Class IV power occurs prior to the poison-out period, to return the unit to service.

The role of the operator during such a transient is to monitor the actions of the emergency transfer system, to intervene when the intended automatic operations do not take place, and to restore the system to its normal operating state once the fault conditions have cleared. These tasks include a significant knowledge component, namely the correct operation of a complex system under a variety of fault conditions, and the ability to perform the approved operations in a timely manner. The acquisition of the necessary knowledge, as well as the development and maintenance of the required skills, were found to be significantly improved by the use of the microsimulator. An experienced operator credited the microsimulator with preventing a unit poison-out soon after he had received refresher training on the system.

In order to encourage the self-paced training aspect of the microsimulator, test items were prepared to verify the level of capability achieved. These exercises included the significant operating events which prompted the development of the microsimulator, as well as a representative set of other malfunction conditions. The trainee could select from a menu of exercises, although the exact nature and number of malfunctions to be encountered would not be known. The trainee would be presented with the initial operating state and the desired terminal objective. When the trainee informed the program that the exercise had been completed, an evaluation of his performance would be reported, along with the option to review the reference operating sequence used as the basis of evaluation.

The microsimulator was installed in the control room, where it could best provide support for on-the-job training. It was also found to be a very useful job aid: unusual operating conditions could be first reviewed between the unit first operator and the shift supervisor with the aid of the microsimulator. Such reviews were found to be useful in selecting the most appropriate operating sequence.

#### Supplement a non-replica simulator

The training program to authorize the first operating crew for Bruce NGS B was not meeting its target by the middle of 1983. A review of the program found a number of important elements of systematic training not in place, particularly performance-based objectives and evaluations.

Based on the experience of delivering training on the Pickering-A simulator to control room staff from other stations, we had recognised the need to acquire separate simulators for each station with significant differences in man-machine interface. However, when a major training problem arose in the authorization of the initial control room operating staff for Bruce-B, one aspect of the extensive corrective actions undertaken was to deliver some overall unit training using the Bruce-A simulator. (At that time, in the middle of 1983, the Bruce-B simulator was in the early phase of manufacture). In order to provide training for Bruce-B systems which were not replicated on the Bruce-A simulator, microsimulations were developed for the more important of these systems.

The turbine-generators for the Bruce-A station were made by Parsons, while the ones for Bruce-B by General Electrics. The control room instrumentation for these two turbines are completely different. In particular, the GE design calls for extensive automatic control, with the operator selecting the appropriate set-points and rates of loading.

The microsimulation was required to allow the warm-up of the turbine, taking it from turning gear to operating speed, load rejection, major on-line tests and a variety of malfunctions. Figure 4 shows the stylized representation of the turbine panel relevant to the required operations. It includes 16 annunciator windows across the top of the screen, and the associated acknowledge, clear and test pushbuttons at the bottom right hand corner of the display. Eleven analog indicating meters give the pressure across the HP turbine, governor control valve and intermediate valve signals, turbine load, load set-point, speed, throttle pressure limiter and warming rate. All the pushbuttons for the required range of operations are represented, including turbine trip, reset and test, load limiting, speed select, starting rate, chest/shell warming, load setting, speed matching and throttle pressure limiting. The upper right-hand portion of the monitor can be assigned alternate functions for training purposes. The example used for Figure 4 shows the changes in key parameters during a controlled unloading maneuver. The same area could also be used to display the panel instrumentation necessary for a particular test.

The trainee can perform a complete start-up, including all relevant tests, responding to uneven warm-up, problems with critical speeds and a variety of malfunctions. From full power operations, a complete load rejection can be performed, followed by either a unit shutdown or a recovery to full power.

In addition to meeting its training mission, the commissioning staff found the microsimulation to be useful in trying out the commissioning procedures. Subsequent to commissioning, the simulation was updated to match the actual field data, and additional exercises were developed to capture key aspects of the commissioning team's experience for subsequent trainees.

## Full-scope simulator update delayed

A high pressure emergency coolant injection (HPECI) system was included in the original design of Pickering NGS-B and subsequent stations. For the two earlier stations, Pickering-A and Bruce-A, HPECI is being retrofitted during planned outages. Due to a combination of design and training concerns, these modifications will not have been completed on the respective simulators until approximately two years after the start of training for these systems. Microsimulations were developed to provide performance-based training for unit first operators and shift supervisors for the HPECI system at both of these stations.

The HPECI system at Bruce NGS-A has three potential sources of coolant water: the high pressure water tanks, the emergency storage tank and the grade tank, plus recovery from the sumps once enough water has collected in them. Referring to Figure 5, the initial source for injection is a group of four high pressure water tanks (H2O TK 3, 4, 5 and 8) powered by two Nitrogen tanks (N2 TK) at a pressure of 5.8 MPa. Normally the two sets of tanks are isolated by MV303 and MV304. The water tanks are connected to the emergency injection headers (ECI #1, #2, #3 and #4 corresponding to the four units) via MV313, 314, 323 and 324. These valves are also closed under normal operating conditions. The next source of coolant injection is the Grade Tank via injection pumps PM21-24. The Emergency Storage Tank provides a back-up in case the pumps are not available.

Once sufficient water has collected in the recovery sumps, they become the source of coolant. Via the appropriate valves, the injection pumps pass the recovered water through the three heat exchangers and into the injection headers. All of the devices and actions described above are automated, and are dependent on such parameters as heat transport pressure, boiler room pressure, reactor power and the signals displayed on the indicating meters shown on Figure 5.

The above portion of the emergency coolant injection system is common to all four units. The equipment downstream from the injection headers exists in each of the four units. Only the unit experiencing the loss of coolant conditions will receive injection.

The unit specific portion is shown in Figure 6. The connection with the common unit is made at the ECI HEADER. In the poised state the H2O injection valves (MV2 and MV3) and the associated bypass valves (MV131 and MV132) are closed. Valves MV101 and MV102 are open, but may be closed to allow on-line testing of the H2O injection valves. A U-pipe with an air gap to separate the light and heavy water sides is installed downstream from the injection valves. The levels in the U-pipe legs are shown on the indicating meters. The separator drain isolation valves MV109 and MV112 on the H2O side, and MV110 and MV111 on the D2O side, are open. The separator air gap is vented through MV113 and MV114. Downstream from the separator pipe there are four non-return valves (NV115-118) and eight motorized isolation valves (MV4-7 and MV13-16).

These twelve valves are closed, isolating the heat transport system from the injection system. The remaining valves are only required during tests of the valves in the injection lines.

During injection the H2O/D2O U-pipe separator vent and drain valves are closed. The H2O injection valves, injection by-pass valves, and the D2O isolation valves are automatically opened while the previously described actions occur on the common unit side. The fast-stroking by-pass valves (MV131 and 132) open to force H2O through the U-pipe separator before the D2O drain valves (MV110 and 111) close. These actions result in a filled system from the H2O injection valves to the non-return valves. Once the motorized valves are open, an unrestricted flow path is provided from the H2O accumulator tanks to the heat transport system header. Injection will occur once the heat transport pressure drops below the injection pressure. Injection in this mode will continue until the injection pressure falls below the recovery pump discharge pressure.

In order to operate the full system, the trainee has to select between the common and unit specific portions of the simulation. This is not unrealistic, since in the actual control room the respective panels are separated by at least 20 feet. Learning and practising which panel has the most relevant information at various stages in the event is an important part of the training.

The operator's job is to monitor the actions of the automatic system and intervene when a required action does not occur, or if an incorrect action had taken place. All the valves and pumps may be operated by touching the designated part of the display. A variety of tests can also be performed. Particular attention has been given to the tests that could result in the inadvertent mixing of light and heavy water.

Full-scope simulator acquisition delayed

The majority of the Darlington NGS process and control systems, as well as the entire control room man-machine interface will be significantly different from previous stations. None of the existing simulators were considered able to provide any performance-based training for Darlington personnel.

All the staff being trained to be authorized as unit first operators and shift supervisors for the first Darlington unit were previously authorized at another station. The training required for this staff has two major components:

- (i) orientation training to learn the equipment and systems that comprise the plant,
- (ii) specific training in the operating procedures that specify how the plant will be operated under standard, nonstandard and abnormal conditions.

The first of these is knowledge training, the second a combination of knowledge and cognitive skills.

In addition to the problems faced due to the many new systems at Darlington, three additional factors contributed to the need to use microsimulators to support the training program:

- (i) operating staff could not be assigned when originally planned because of staff shortages and work delays at other stations,
- (ii) design documentation was late and the designs of major systems were undergoing changes,
- (iii) the full-scope simulator (for reasons similar to the above) would not be completed until three years after the start of the station training program.

The development of microsimulations is also very difficult in the absence of station design information. The task was made possible because the staff developing the software models were suitably trained, and had experience in the operation of CANDU generating stations. They were able to work from design intent reports and feasibility studies to construct the basic models. By working closely with station commissioning staff, they could make the models operational according to the most recently issued design information. This process not only made the simulations available for training in the minimum time, (within approximately three months of the issuing of design information), it was also of significant help to the commissioning engineers to gain insight into the intended operation of key systems. As a result of some of the microsimulations, design problems were identified much sooner than if the usual commissioning approach had been followed.

The initially developed microsimulations of course had to be modified as the design became finalized. Thanks to the training and experience of the commissioning and simulation development staff, these changes were not extensive. As the operating manuals are becoming available, the microsimulations are being reviewed to ensure that their responses are consistent with the actions called for in the operating manuals. The initial reviews indicate that the simulations will not require significant changes.

The microsimulations are used in two ways to support station system orientation training:

- (i) the instructor uses the microsimulation as a dynamic training aid to demonstrate the interactions of equipment and systems, as well as the changes in major process, control and safety system parameters;

- (ii) the trainee uses the microsimulation in self-study, to learn the information at his or her own pace, reinforcing the knowledge by doing relevant operating exercises.

In order to achieve effective training it is important that the demonstrations be preplanned integral parts of the lessons, and that the self-study exercises be similarly planned and documented.

The microsimulations will have one additional role to the above in the operating skills portion of the training program. Apart from being a demonstration tool and a self-study medium, the microsimulations will also be used to verify each trainee's ability to perform the approved operating procedures under standard, nonstandard and abnormal conditions. These evaluations are currently planned to be conducted by the instructors, although they could be automated in the future. Currently 12 units are in use at the station, one per two trainees. This level of resourcing has been found to be appropriate, since typically a trainee needs a terminal approximately 50% of the time.

For Darlington NGS the following microsimulations have been developed:

- Reactor Regulating System.
- Heat Transport Pressure and Inventory Control.
- Negative Pressure Containment.
- High Pressure Emergency Coolant Injection.
- Boiler Level Control.
- Boiler Pressure Control.
- BBC Turbine Auxiliaries.
- Shutdown System #1 and #2.
- Unit 0 Emergency Transfer.
- Unit 2 Automatic and Emergency Transfer.
- Emergency Power Supply.
- Standby Generator and Auxiliaries.

It should be noted that each of the above microsimulations is for a major system, or a group of closely related systems. Several additional systems are currently under development. We are also planning to develop a module for integrated unit operations, to show the magnitude, direction and approximate rate of change for the key process and control parameters during major transients. A separate module is being planned to allow practise in diagnosing the events and performing the initial operator actions called for in the abnormal incident procedures.

We believe that a well designed and conducted training program, with the necessary written examinations to verify knowledge objectives, and a combination of field training and microsimulator based training will assure that the previously authorized staff will have achieved the skill objectives to commission and operate Darlington NGS.

## Other Applications

The examples described so far in this paper have all related to the training of staff involved in the operation of nuclear generating stations, with an emphasis on how to supplement full-scope simulator based training. Once all five full-scope simulators are in service, the role of microsimulators in operator training will change significantly, as our emphasis moves from the staffing of new stations to optimizing the capability of the existing resources. At the same time, the microsimulation techniques we have developed are finding applications in fields other than nuclear station staff training.

## Tritium Removal Facility

The concentration of tritium in heavy water increases with continuous exposure to neutron flux. This results in an increasing level of radiation hazard to the individuals working with, or in the neighbourhood of, tritium. Ontario Hydro has decided to acquire the means to remove tritium from heavy water. Although the prime purpose of this program is dose reduction, we may sell tritium on the commercial market.

The Tritium Removal Facility (TRF) currently being built on the Darlington NGS site is the first of its kind in Canada. The training of Ontario Hydro's staff to commission and operate this facility has faced unique problems. In addition to having no previous experience with this type of process, the control room equipment chosen for the facility is also the first of its kind. The facility will be controlled by a Fisher and Porter DCI4000 digital computer control system. It has a custom keyboard and colorgraphics CRT monitors as the man-machine interface.

A task analysis of the control room operator's job confirmed the need to provide performance-based training for this position. The microsimulator approach was chosen for several reasons: the level of process system modelling was within the capability of a microcomputer, the monitors used by the DCI4000 were identical to the ones used in the microsimulators already acquired for Darlington NGS, and the overall cost could be minimized because of the existence of many of the required software routines.

The training package we developed consists of an overview and seven individual system simulations. There are 65 different displays with over 250 inputs and outputs. We were able to acquire the special purpose keyboard, thereby turning the microsimulations into true part-task trainers: both the physical and the functional characteristics of the real system have been replicated. In the future, by interconnecting three monitors and the seven system simulations, a full-scope replica simulator for the TRF control room could be realised.

## Plume Tracking System

The process by which heavy water is separated from light water uses H<sub>2</sub>S. This is a highly poisonous gas in concentrations above 50 ppm. Elaborate safety procedures are in place at the Bruce Heavy Water Plant to protect both workers and the public from inadvertent releases. Forty detectors are installed on the site and seven off the site, and these measurements are available in the control room. At the present time hand-held calculators are used to predict the concentrations at various points, based on the assumed place and size of the release, the weather conditions and the actual detector readings. This approach is cumbersome, error-prone, gives only a few values and does not provide a satisfactory overall view of the evolution of a release.

Units are available on the market to compute and graphically display the spread of certain gases at a variety of concentrations. These could not be used directly for the display of information needed at the heavy water plant. Modifying the existing units was more expensive than developing them in-house. An independent evaluation of internal capability resulted in the section responsible for microsimulations being selected to develop the plume tracking system. In addition to the specified display of actual releases, the system we developed includes a training mode, during which simulated conditions can be investigated and the responses to them practised. If a real event were to occur during a training session, the computer would sense the conditions, terminate the training exercise and display the actual data. A system similar to this, to be used for tracking radioactive releases, is likely to be developed in the near future.

## Thermal Plant Operator Training

The microsimulations developed for the nuclear generating stations using Parsons, GE and Brown-Boveri turbines can also be used at the thermal plants having similar units. We are currently investigating the extent of changes, if any, required to adapt the microsimulations for the training of thermal operators. Because of the many thermal plants and the variety of control room instruments used, the building of replica full-scope simulators would be very expensive. We are recommending the use of a multi-CRT approach, using touch sensitive screens and stylised instrument displays to configure a simulator which could be full-scope in a functional sense, and be adaptable to closely replicate a wide range of control rooms by changing the software only.

## Job Aids

The plume tracking system for the heavy water plant, and to a certain extent the Douglas Point NGS electrical system simulation, are examples of job aids. These microsimulation-based devices were installed in the control room, and the operators could use them to perform their jobs more effectively and more efficiently. Computers and colorgraphic displays are increasingly utilized in the control rooms of nuclear and other

plants. The addition of simulation techniques and other "intelligent" programs are expected to help the operator to improve plant performance while at the same time meeting higher regulatory requirements.

A particular area of application we are considering is the simulation of computer and other "black box" controllers. The algorithms of these systems are often highly complex and their documentation difficult to follow. A simulation could "open up" such a system, allowing the station staff to gain additional insight into its operation, and permitting them to test proposed modifications and procedures. Although such simulations cannot be considered to replace design analysis and thorough knowledge of equipment, systems and science fundamentals, they have shown themselves to be a very useful tool for the operating staff.

### Self-paced Training

To-date we have found that the most effective way to utilize the microsimulations is to first let the instructor use it as a demonstration tool, followed by self-study and finally as the medium for performance-based testing. As the use of microsimulations becomes more wide-spread and, coincidentally, class sizes shrink, we expect increasing emphasis to be placed on self-paced training. Much of this would take place on-the-job, during the regular shift. The individual's supervisor would act as the subject matter expert, giving guidance and additional information as needed. The computer would assure consistency of training and performance, without removing the trainee from the work environment. Refresher training could take place where and when it was required to perform a particular job. A significant increase of self-paced computer-based training and the use of job aids could prevent the formation of an additional shift crew to cope with upgrading and refresher training, and other increases in work load.

### CONCLUSION

The microsimulations described in this paper have been used to support Ontario Hydro's nuclear training program for the last seven years. They have been found to be a useful tool, along with conventionally equipped shops and full-scope simulators, to provide performance-based training. Microsimulations supplement full-scope simulators in the area of individual system training, both to acquire the knowledge of how complex systems behave and to demonstrate the skills required to operate such systems according to the approved procedures. For plants and systems for which the cost of a full-scope simulator cannot be justified, but which cannot be operated for training purposes, microsimulators offer a viable alternative.

The increasing use of computers in generating stations and other complex industrial plants, along with the improved capabilities of micro-computers, will offer new opportunities to improve the performance of workers. Some of these improvements will occur in training while others as a result of better job aids. As shown in this paper,

microsimulation is a technique that can be used to realize such improvements.

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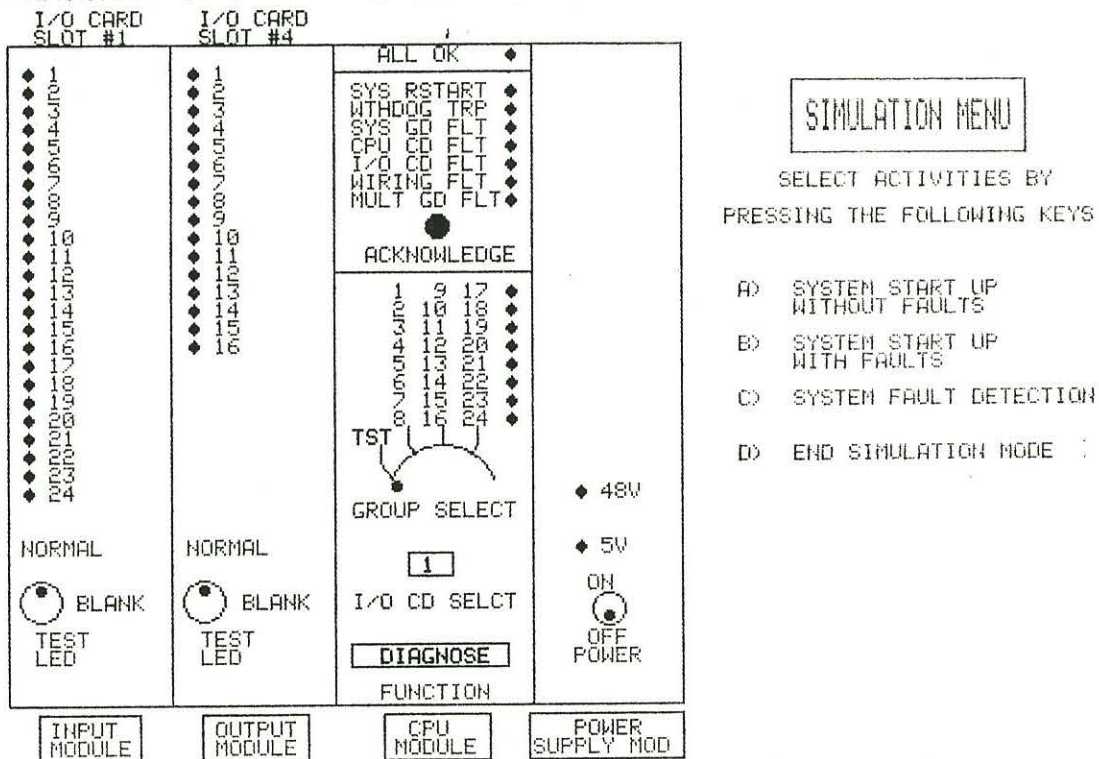


Figure 2. OH180 Programmable Controller.

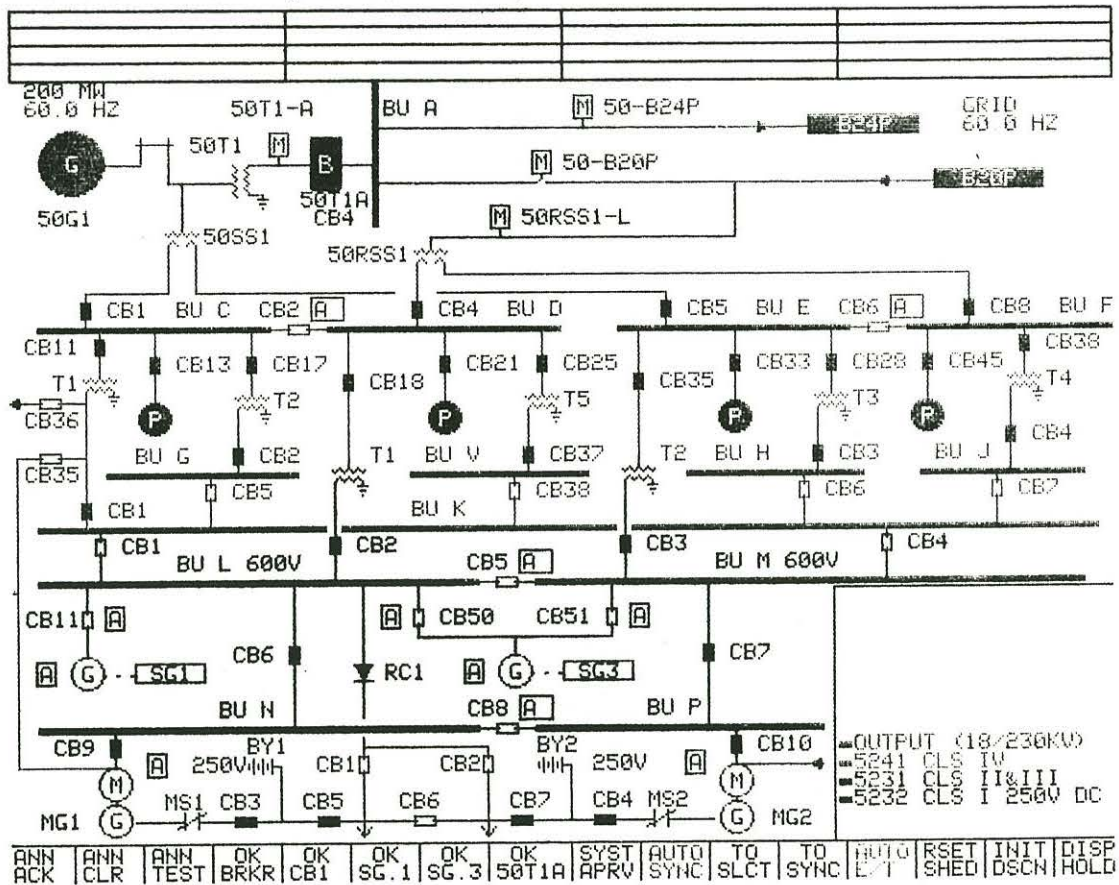


Figure 3. Douglas Point NGS Electrical System.

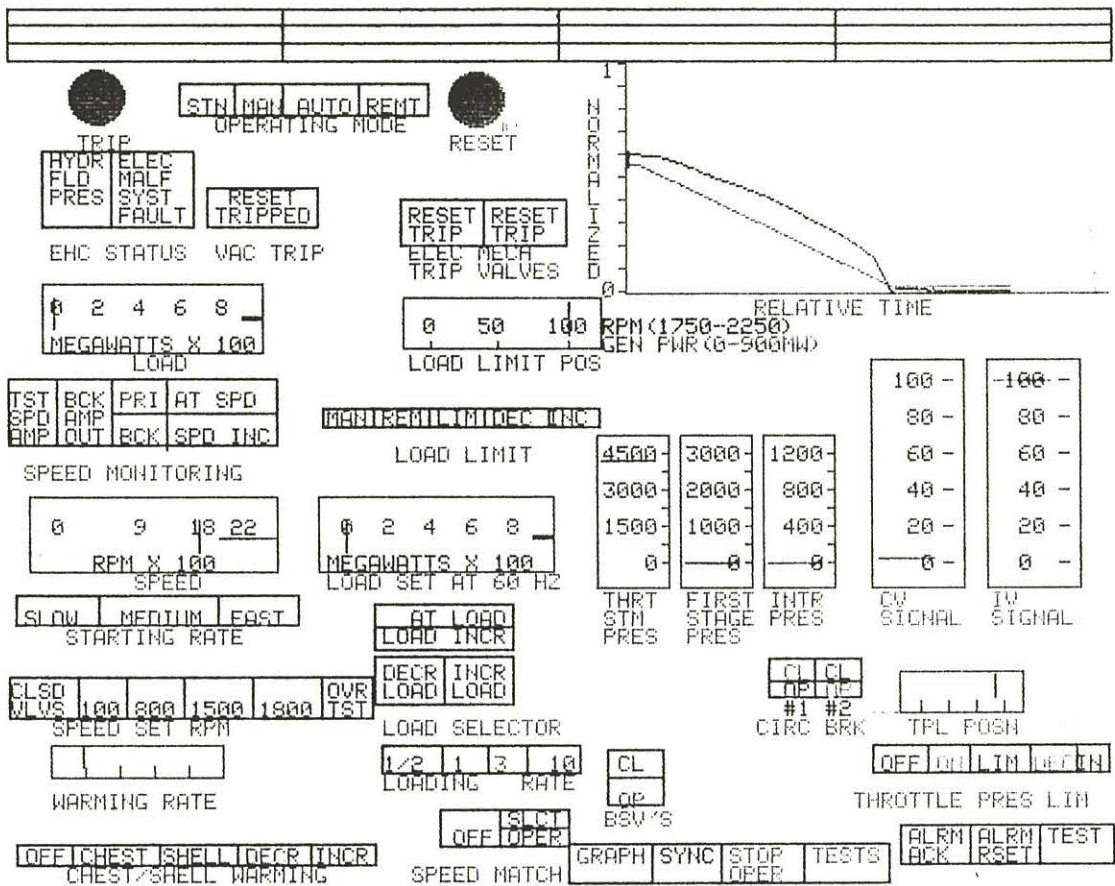


Figure 4. Bruce NGS-B Turbovisory Panel.

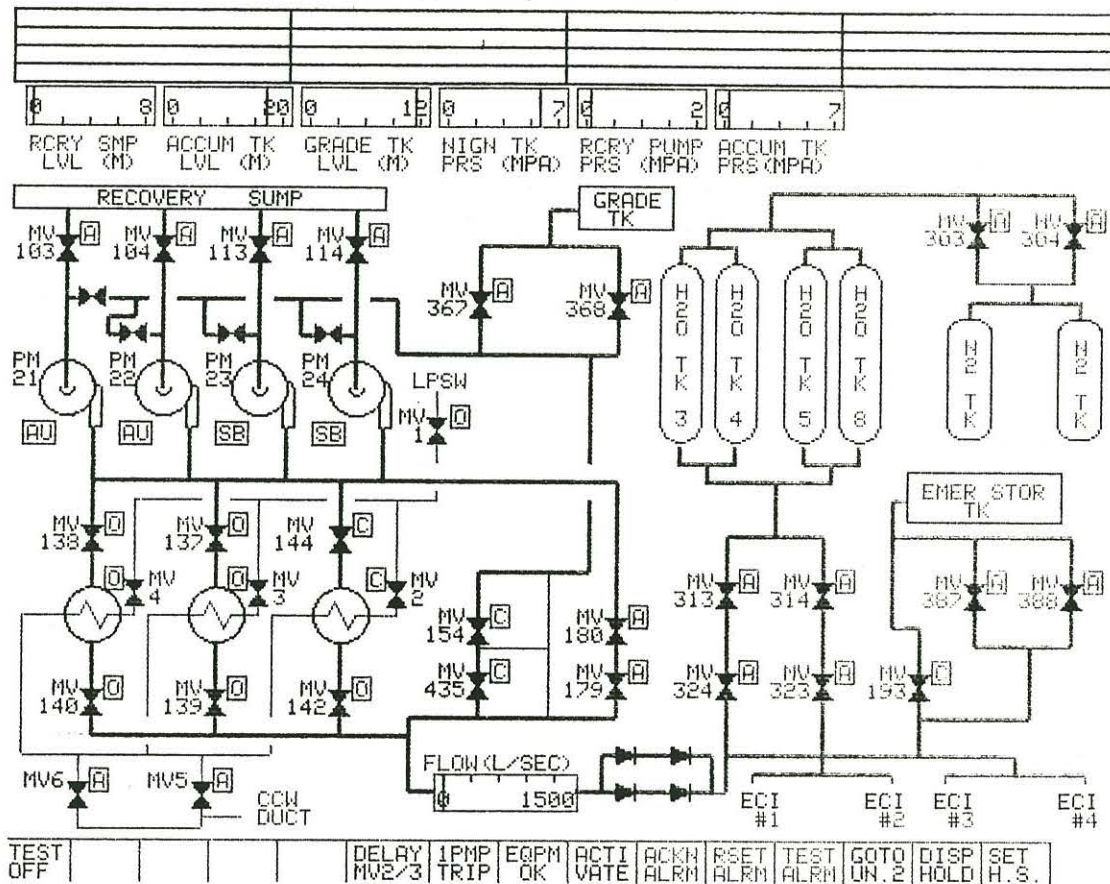


Figure 5. Bruce NGS-A HPECI, Common Panel.

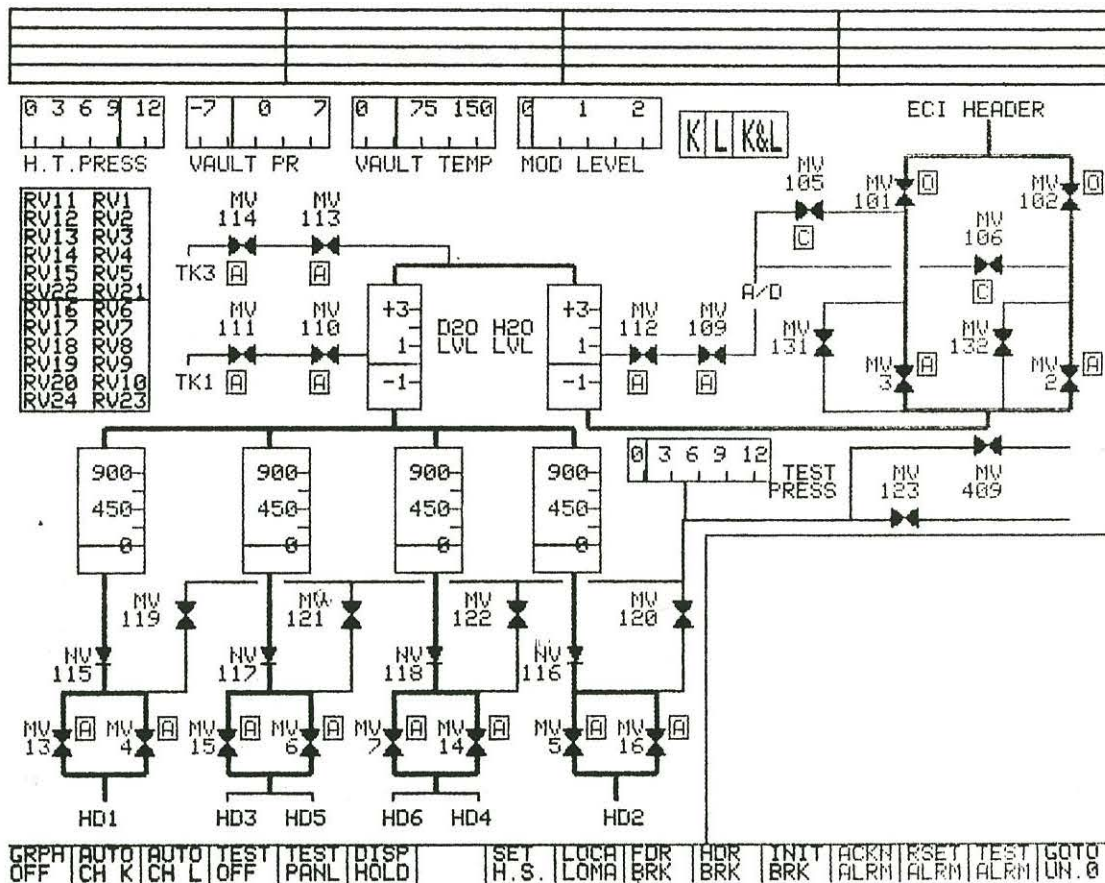


Figure 6. Bruce NGS-A HPECI, Unit Panel.

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