CANDU 9 CONTROL CENTRE MOCKUP

A. WEBSTER, M.J. MACBETH

AECL
446A Second Ave. North
Saskatoon, Saskatchewan, Canada, S7K 2C3

ABSTRACT

This paper provides a summary of the design process being followed, the benefits of applying a systematic design using human factors engineering, presents an overview of the CANDU 9 control centre mockup facility, illustrates the control centre mockup with photographs of the 3D CADD model and the full scale mockup, and provides an update on the current status of the project.

INTRODUCTION

The next generation CANDU control centre is being designed for the 900 MWe CANDU 9 station. This design includes the enhanced functionality of existing CANDU control centres, advanced features made possible by new technology, and addresses characteristics required by human factors analysis of control centre operations. Recent statistics show that up to 70% of plant significant event reports have a root cause attributable to the human from such sources as complex systems, interfaces, procedures, maintenance and management practices. Consequently, special attention is being given to the human factors engineering (HFE) of the control centre. To achieve this, a mock-up of the control centre panels and consoles in the Saskatoon office facilities will be used for verification and validation of the control centre features, displays and operator interactions. The control centre mock-up exists as a CADDS model as well as a physical full scale replica.

The goals of the control centre design team is to successfully integrate all control room interfaces into one functional system including the control room staff, the human-system interfaces, the operating procedures, the shift management and resources. The control centre is generic to any size CANDU reactor, whether based on the successful CANDU 6 (700 MWe) unit or the larger CANDU 9 (900 MWe) reactor. This integrated control room allows the CANDU nuclear power plant to be operated safely and efficiently over all plant operating regions as well as during abnormal or upset conditions.

The control centre mockup will address these goals by:

- dynamically evaluating human system interface designs using simulations.
- proving and developing operator monitoring, decision-making and controlling interfaces.
- providing the means for verification and validation of both the human system interface designs and operator "critical" actions from aspects of human performance.

CONTROL CENTRE DESIGN PROCESS

The CANDU 9 design process follows a systematic analytical approach of system design with requirements definition, function analysis, function allocation and task analysis, combined within a verification and validation cycle, to define operator information and information presentation requirements in the control centres. The control centre mockup is utilized throughout all aspects of the design process.

Function allocation is considered early in the requirements definition stage as designers are guided to consider, for example, if the function should be performed automatically or manually (i.e. allocated to machine or human) and if automatic, should that function be performed by computer or hardwired devices. The procedures, design guides and the reference plant basis assessment documents aid the designers in this allocation. Further function allocation details are defined as the system design description is prepared. A function analysis design guide is used by the CANDU 9 designer to progress the on-going design review/evaluation process to ensure that required operational sequences can be conducted effectively and efficiently.

At the early stages of the design, it is sufficient that the designer identifies and documents the high level functions and interfaces as well as the high level allocations for those functions. As the design proceeds, this information can be revisited and completed to a greater level of detail so that such details as automatic/manual, location in main control room/secondary control area, process/safety/post accident monitoring/critical safety parameters, VDU-based or hardwired, plant operating regions, etc, can be addressed.

The resultant operator display, annunciation and control information is verified against the system design requirements to provide a high confidence level that adequate and correct information is provided , necessary for the operational task at hand. This verification process includes the traditional supervisory and peer document reviews, CADDS reviews, procedural walk-throughs and evaluations by utilizing the physical full scale panel mock-up facility which is supported by the PC-based CANDU 9 plant simulation. The CANDU 9 control centre mock-up provides an important part of the design process allowing design details to be assessed statically or dynamically to ensure the operability, effectiveness and efficiency of selected design features.

CONTROL CENTRE MOCKUP FACILITY

The control centre mockup facility consists of the following major components:

Control Centre Design Modelling

The CANDU 9 control centre mockup exists as a 3D CADD and also as a model full scale mockup facility. The 3D CADD model is a scaled representation of the mockup and equipment located in the mockup room. The model was developed using an Intergraph VE500 workstation running Modelview software. The 3D CADD model has evolved from the reference control centre design to the proposed CANDU 9 layout providing designers with an auditable trail as the control centre layout is revised.

Before any panels or consoles were purchased for the mockup facility, all conceptual designs and layouts were evaluated in the 3D CADD model. This translated into a cost effective method for procurement and installation of the mockup equipment. As the mockup facility design is updated, the 3D model is constantly kept up to date with the latest revisions.

The 3D model provides a tool to simulate various control centre lighting and shadow effects based on the placement of lighting sources and equipment. Also animation of a CADD Person is used to simulate the movements and views of the operator when performing task and link analysis on the various systems. This will be invaluable, as the task or link analysis on the 3D model can be videotaped and played back for further study.

The Mockup Facility Room

The CANDU 9 control centre mockup room has almost the same operations area as the actual CANDU 9 plant layout. This area encompasses the main control room panels, the main operating console (MOC), the safety system console (SSC), the fuel handling operators console (FHOC) , the shift interrogation console (SIC), the distributed control system (DCS), the plant display system (PDS) and the plant simulator. The room is approximately 9 by 13 meters with a glass viewing area along one wall. A separate heating and ventilation system provides an environment very close to that of an actual control room. Separate power supply feeds and network cabling allow failure mode scenarios to be demonstrated on the mockup hardware and software systems. The room is carpeted, has a drop ceiling to provide a realistic working environment and is equipped with variable lighting controls which can be modified based on the input from the 3D CADD model or the actual scenarios conducted in the mockup.

MAJOR COMPONENTS OF THE PHYSICAL MOCKUP

Safety System Console (SSC)

The SSC is located in front of the Group 2 safety system main control room panels. The console and all attached equipment allow a clear view for the operator from the normally seated position. This is a VDU-based display system using the PDS hardware platform. The SSC console is adaptable by design as the console frame is constructed of unistrut rails and multi density fibreboard (MDF) skins. This modular construction approach allows the console to be modified in size or shape, providing the needed flexibility for a mockup prototype.

The SSC is capable of the following mockup support features: VDU's for testing and monitoring of the safety systems, keyboard, trackball, mouse or other pointing device support, alarm acknowledge and reset capability, power supply enable handswitch for testing, plant communication capability and printing facilities. For the mockup only, the SSC is networked to the MOC, FHOC, DCS, Simulator and the main control room panels. This permits the use of a common database for the mockup.

Main Operating Console (MOC)

The MOC is located in front of the Group 1 main control room panels adjacent to the SSC. The MOC is also a VDU-based display system using the PDS hardware platform. The console is of the same construction as the SSC.

For the mockup, the MOC is networked to the SSC, FHOC, DCS , simulator and the main control room panels. This permits the use of a common database for the mockup. An annunciation interrogation capability using CRL's CAMLS (CANDU annunciation message list system) technology is included in the MOC.

The MOC is capable of the following mockup support features: VDU's for nuclear steam plant (NSP) and balance of plant (BOP) control and monitoring functions, keyboard, trackball, mouse or other pointing device support, alarm acknowledge and reset capability, pushbutton for setback, plant communication capability, space for shift turnover activities, annunciation interrogation workstation, garage for housing a portable VDU and printing facilities.

Fuel Handling Operators Console (FHOC)

The FHOC is also a VDU based display system using the PDS hardware platform. The console utilises the same construction technique as the SSC and MOC.

The FHOC is located in front of the fuel handling main control room panels, to the right of the MOC. For the mockup, the FHOC is networked to the MOC, SSC, DCS, simulator and the main control room panels. This also permits the use of a common database for the mockup.

The FHOC is capable of the following mockup support features: VDU's for fuel handling control and monitoring functions, keyboard, trackball, mouse or other pointing device support, alarm acknowledge and reset capability, plant communication capability and printing facilities.

Main Control Room Panels

The main control room panels are full size construction with a rigid unistrut steel frame, and are designed to accommodate full size replaceable faceplates made of MDF. The faceplates are mounted to the frame with velcro to facilitate ease of replacement and modification during the prototyping phase. The steel frame is constructed to maximize strength and flexibility while providing a full size work area to prototype cable routing and distribution to panel mounted devices.

Faceplate loading capabilities are such that the required number of active panel devices (handswitches, annunciators, meters, control stations and VDU's) can be mounted on the panels. These panel mounted devices are integrated with the PDS, DCS, simulator and fuel handling systems to form the mockup facility.

Full size reference plant panel photographs (photoplots generated by CADD) are mounted on all the panel faceplates and integrated with the active mounted devices which are driven from the DCS or simulator. The photos are laminated to facilitate system analysis visually by using dry erase markers and marking the changes or conceptual ideas directly on the panel surface.

The following systems are located on the main control room panels: Group 2 electrical, Group 2 safety systems, Group 1 NSP systems, central overview display, BOP systems, Group 1 electrical systems and fuel handling systems.

Annunciation System

The control centre mockup utilizes the CAMLS annunciation technique. CAMLS provides new alarm processing concepts and features.

CAMLS consists of two central VDU's to highlight the current fault messages by priority and the state change messages listed by time. The faults are presented on one dedicated VDU while the state changes are presented on the other VDU.

A console mounted annunciation interrogration workstation (AIW) is used to query the annunciation messages. These display systems allow detection of significant plant problems and improve operator awareness of plant state. CAMLS reduces operator mental and physical workload while improving operator performance of procedure and information search tasks.

Central Overview Display

The control centre mockup includes a central overview display which consists of a 67 inch projection screen installed in the central main control room panel . The display presents a dynamically driven overview of the the major systems and components of the station (eg. reactor, primary heat transport, boilers, turbine, generator, etc). The plant systems and major components schematic uses colour to embed system boundaries, special operational functions or energy flow. Control centre staff must be able to quickly identify plant features and functions from the display. The operator is capable of navigating from the display to present detailed information for a particular system.

OTHER SYSTEMS IN THE CONTROL CENTRE MOCKUP

CANDU 9 Mockup Power Plant Simulator

Simulation has been integrated into the CANDU 9 control centre design. The power plant simulator for the CANDU 9 mockup is a low fidelity, part-scope simulator that is designed as an integral part in the design and verification process. The simulator employs dynamic mathematical models of the process and control components that make up a nuclear power plant. The simulator also provides the flexibility to add, remove or update user-supplied component models.

Specific segments of the model can be upgraded to reflect the detailed response to events required to fully evaluate design alternatives. For example, the feedtrain portion of the model has been upgraded to include the process and sensor response to events such as loss of feedwater. This allows the designer/evaluator to initiate an event such as a partial loss of feedwater (without forewarning to "plant" operators), and evaluate the human factors aspects of the annunciation system, other plant displays and operator menu design, as well as panel layout and design and operator procedures, based on the performance of the "plant" operators in response to the event.

The simulator also provides CANDU plant process dynamic data to the PDS, DCS and the mockup panel-mounted devices during the initial and advanced phases of the design stage. The simulator contributes dynamic *points* for the control database to the PDS. Display screens with dynamically changing point values can be configured for the consoles, main control panels and the central overview display. The Inter-Module diagram of the mockup is shown in Figure 1.

Distributed Control System (DCS)

The mockup has an Asea Brown Boveri (ABB) DCS prototype that provides designers with a working functional partition, identical in features to those planned for the CANDU 9 DCS. The DCS prototype is networked to all other systems in the mockup such as the simulator, MOC and external input/output hardware used to drive and receive signals from the panel mounted devices on the main control room panels.

The DCS prototype will be used in the mockup to verify the integration of the component architecture that makes up a full DCS partition. Software development tools for DCS will be assessed and a prototype plant control code will be prepared and executed against a plant simulation, to demonstrate the systems capabilities. Interfaces between DCS and other control centre systems (PDS, main control room panels etc) will be developed and tested.

The completed prototype system will be available in the mockup for further control software development and testing as the system design is finalized.

Plant Display System (PDS)

The various consoles and the main control room panel mounted VDU's described above will all be integrated as part of the plant display system (PDS). The mockup PDS comprises a global database node. together with a gateway node for each of the systems that are integrated in the mockup. The PDS interfaces are to the plant simulation, the CAMLS annunciation system, and with the DCS.

DESIGN UTILIZATION of the MOCKUP

The following points outline the CANDU 9 design strategy regarding the key uses of the main control room mock-up:

- General layout and orientation confirmation:
  - consistency with station function and energy flow
  - visibility of panel devices and functional access to those devices
  - consistency with the annunciation strategy
  - implementability of the proposed hard/soft philosophy

- aesthetics, acoustics, access, lighting

- System panel details:
  - confirm adequate allocations
  - verify system indications, alarms, and control
  - confirm features of the central overview display
  - confirm correct 'range-of-control' for human interfacing actions
  - verify adequacy of auxiliary support and PAM devices

- Operator console details:
  - confirm operator communications capabilities
  - confirm line of sight and readability
  - verify console VDU display suites
  - confirm range-of-control activities (annunciation, testing, setbacks, procedures, overview display, etc)

- Validate MCR tasks and activities:
  - test PDS/DCS/panel information integration
  - evaluate device maintenance capabilities
  - confirm console vs panel operation task allocations
  - confirm major operational sequences such as warm-up or cool-down
  - evaluate event information completeness
  - evaluate functionality of the central overview display

PROJECT STATUS

At the time of writing this paper, the CANDU 9 control centre design requirements document has been approved and issued for use. The control centre design has undergone a formal peer review, including external staff expert in operations and commissioning. The control centre operational feedback meeting with the reference station staff has also been completed. The control centre design requirements information sessions have been conducted with the Canadian nuclear regulatory authority (the AECB). The associated control centre design documents (such as plant display, control centre, distributed control, HFEPP, operational philosophy, etc.) have also been approved for project use and have been submitted to the AECB for review with completion of the corresponding information sessions. Phase I of the CANDU 9 control centre mockup and plant simulator has been completed. It is anticipated that all supporting mockup software and hardware will be completed to allow design verification activities by early 1997.

The control centre design is on schedule and will be a significant contributor to the safe, effective and efficient operation of the CANDU 9 power plant ensuring that the CANDU 9 will continue the world leading electrical generation performance of preceding CANDU stations.

In the mockup, the main control room panels currently have two hardwired annunciators, eight VDU's and a large screen central overview display mounted in the panel bays to allow functional demonstrations of control centre operational tasks.

REFERENCES

Journal or Conference Paper

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(2) MACBETH M.J. , WEBSTER A. , "Improved Operability of the CANDU 9 Control Centre", 11th KAIF Annual Conference, Seoul, Korea, 1996, April

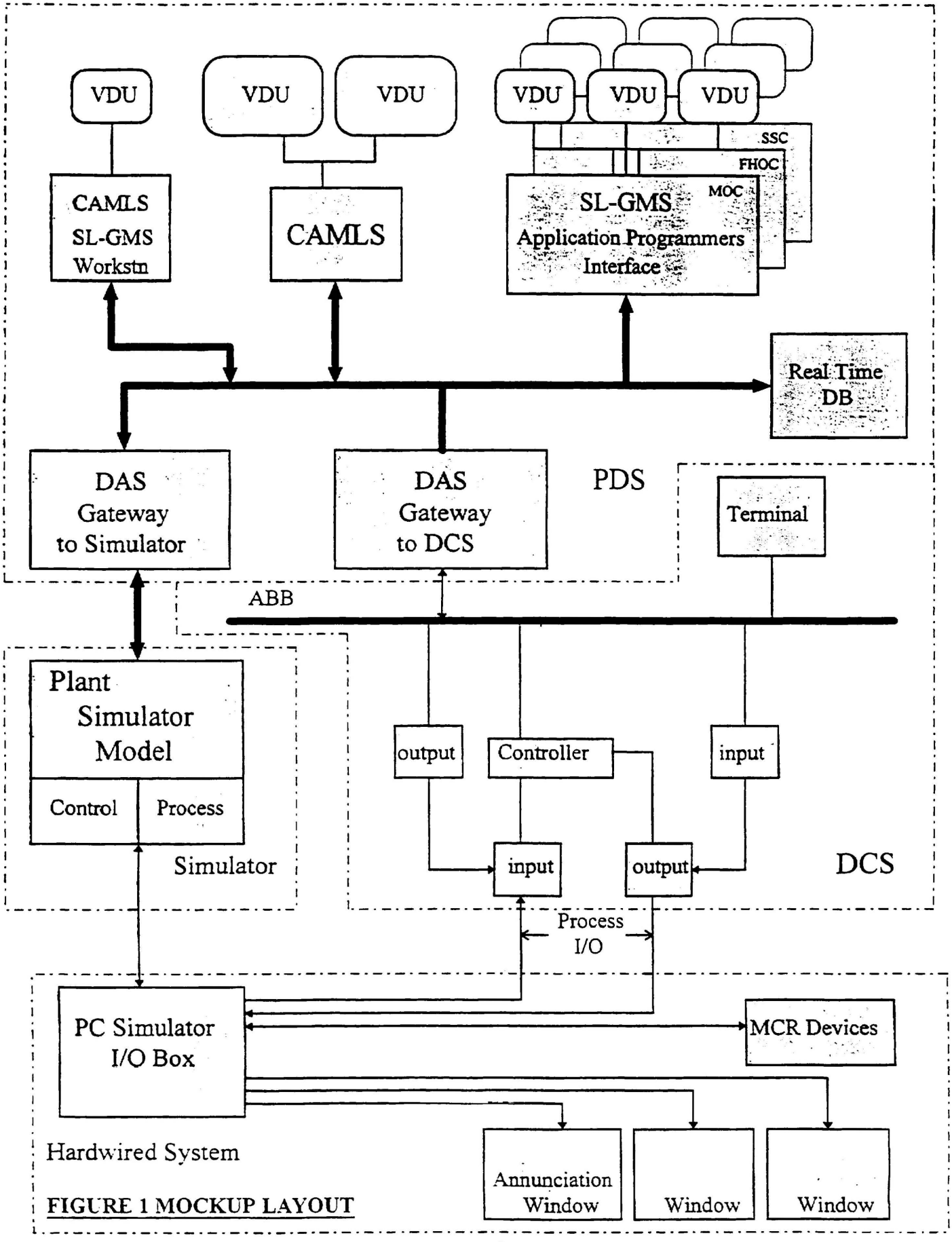


FIGURE 1 MOCKUP LAYOUT

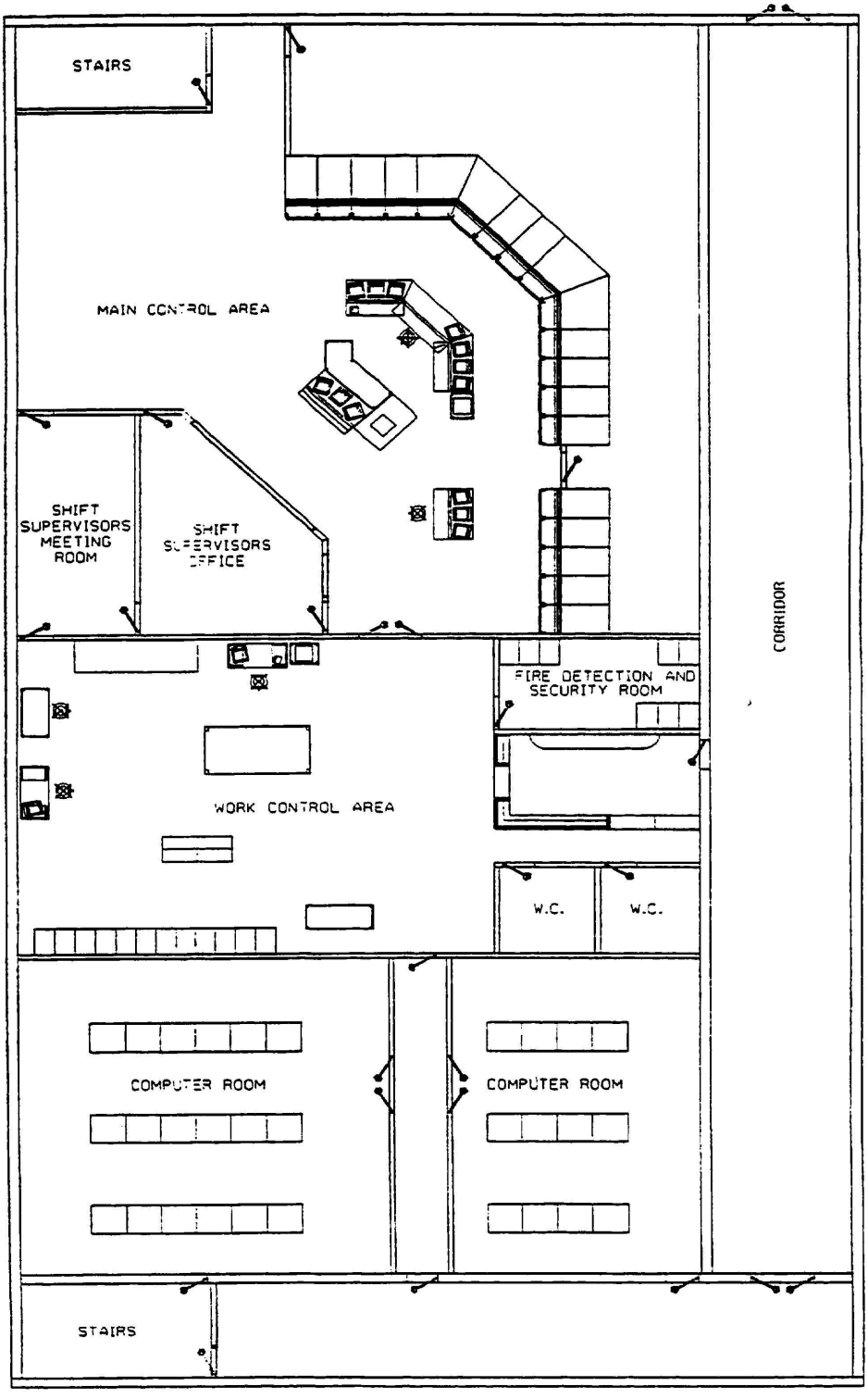
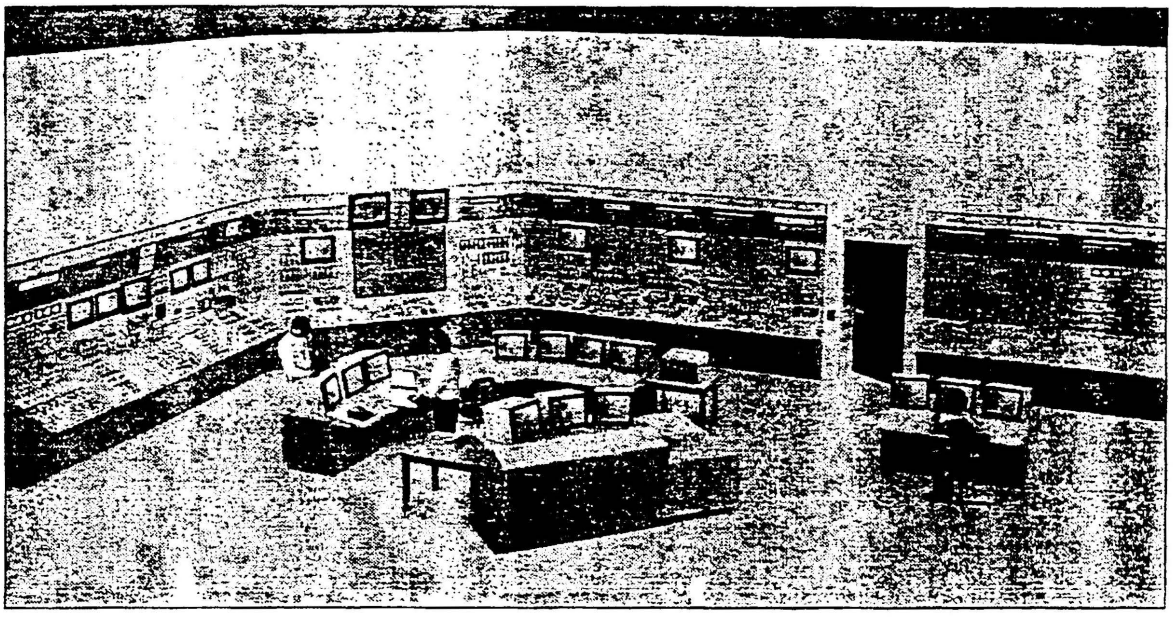
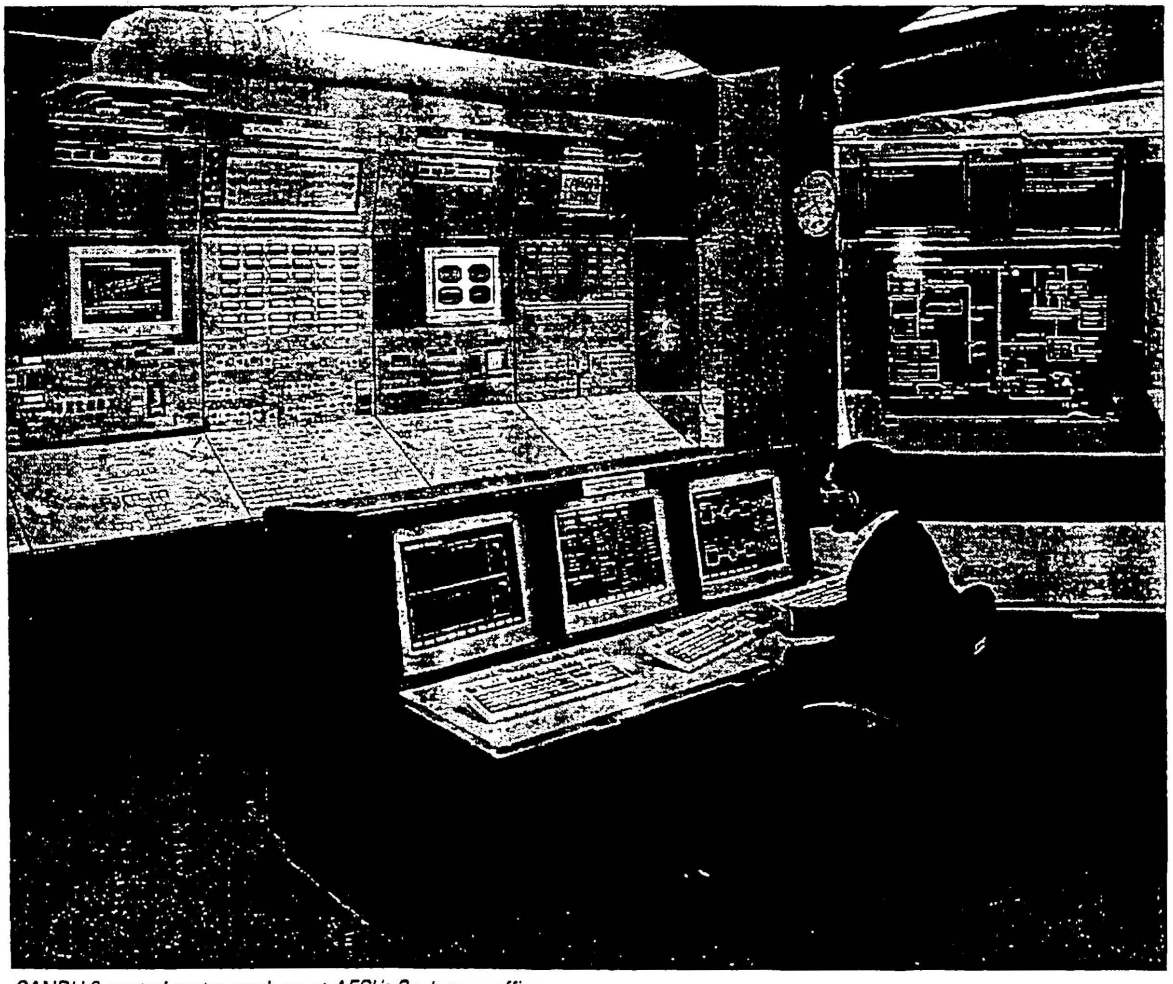


FIGURE 2: CANDU 9 CONTROL CENTRE LAYOUT



CADDS image of CANDU 9 control room.



CANDU 9 control centre mock-up at AECL's Saskatoon office.

Figure 3