ADVANCED CONTROL AND OPERATOR INTERFACE SYSTEMS FOR CANDU 9 FUEL HANDLING SYSTEM

D. Arapakota and A. Xing

Atomic Energy of Canada Limited
2251 Speakman Drive
Mississauga ON Canada

ABSTRACT

One of the goals of CANDU 9 plant design is to provide an advanced, state of the art control system and an operator friendly human machine interface to assure error free operation of the Fuel Handling (F/H) system. This system is an evolution from CANDU 6 retaining its proven strengths. Extensive operational experience feedback from CANDU stations was utilized in the design of these systems.

An important decision made for the CANDU 9 is that the control functions and operator interface functions are separated into two systems, while providing a tight coupling between them. Another important feature is that F/H control and display systems are part of the overall plant wide control and display systems network while providing full functional and operational independence from the rest of the plant control and display systems.

The CANDU 9 F/H control system uses a modern Distributed Control System (DCS) to perform all mechanism controls, process control, sequential control and operational interlocks. An independent hardwired system is provided for safety related interlocks. The system is partitioned and distributed on the basis of natural arrangement and relationships between various F/H equipment. Redundancy is provided where necessary for operational reasons. In addition, extensive system monitoring and diagnostic facilities are provided to minimize system down time. A seismic trip system is also incorporated to avoid inadvertent operation of the F/H equipment in the event of any seismic activity.

The F/H Display System (FDS) provides the human-machine interface functions primarily through a sit-down F/H operator's console. All normal, abnormal and emergency F/H operations are carried out from this console through 4 CRTs, which provide control and information display functions. The display system provided at this console is designed based on strict human factors guidelines to provide a user friendly and task oriented operational environment. The F/H operator has quick access to all the F/H information through a context sensitive display navigation system. The displays are predominantly graphical and require minimal data entry by the operators. Two additional alarm CRTs and a sophisticated annunciation interrogation facility are provided for fault indication and quick diagnosis of F/H problems.

A hardwired backup control panel with limited control and monitoring functionality is provided to put the F/H system in to a safe state in case of unavailability of either the F/H DCS or the FDS.

Specific features used in the design of CANDU 9 F/H control and operator interface systems are (1) to provide standardization with rest of the plant and (2) to utilize open systems standards and commercially available hardware and software components to build the system.

These systems are also designed for easy application to evolving new CANDU plant designs as well as for retrofit applications to the existing CANDU stations.

INTRODUCTION

The fuel handling (F/H) system in existing CANDU 6 plants was designed in the early 1970's utilizing the technology available at that time. The system was designed to operate in full automatic mode through a centralized Digital Control Computer (DCC-Y), which also performs main plant control operations. A significant number of control and monitoring functions used conventional control hardware such as relays, current alarm units, analog controllers, etc. No redundancy was provided for the fuel handling control functionality. DCC-Y also handled fuel handling operator interface functions. Operator interface was provided through a hardwired control panel for manual control (using hardwired switches, push-buttons and indicators) and two CRTs (Cathode Ray Tubes) for automatic control. The displays were primarily text based. This design has proven to be adequate in meeting the basic control and display requirements. However, the sharing of the F/H control and display computer with the main plant control computers has resulted in some operational limitations for the F/H system.

AECL has taken an evolutionary approach to the CANDU 9 design. Underlining this approach is a refined engineering design process that effectively integrates operational feedback and human factors engineering to define the control and information presentation requirements. In CANDU 9 design, the F/H control and display systems are functionally independent of the rest of the plant control and display systems to provide maximum operational flexibility for the F/H system. A further advantage of the distributed design is to allow approved control, display and annunciation software changes to be implemented without causing any impact on the rest of the plant control and display systems and vice versa. F/H display functions are separated from the control system. This strategy of separation allows powerful non-proprietary computers without application memory constraints or execution limits to provide extensive control, display and annunciation enhancements within an open architecture.

THE FUEL HANDLING SYSTEM OVERVIEW

A simplified block diagram of the fuel handling system is shown in Figure 1.

An advanced distributed control system is used for the CANDU 9 fuel handling control system. Both supervisory control and low level device control are handled by the distributed control system. The control and monitoring functions are distributed among a number of digital controllers which are connected by high speed redundant communication links. The control functions are implemented in a three level hierarchy comprising supervisory control, subsystem control and individual device control. Redundancy is provided for the control of selected equipment.

The CANDU 9 fuel handling display system uses a state-of-the-art technology for operator interface such as display, annunciation, data logging and reporting. It provides the primary interface between the fuel handling operator and the fuel handling system.

The FDS acquires data regarding the state of the fuel handling equipment from the fuel handling control system. The fuel handing display system is a subsystem of the plant-wide display and monitoring system in the control centre.

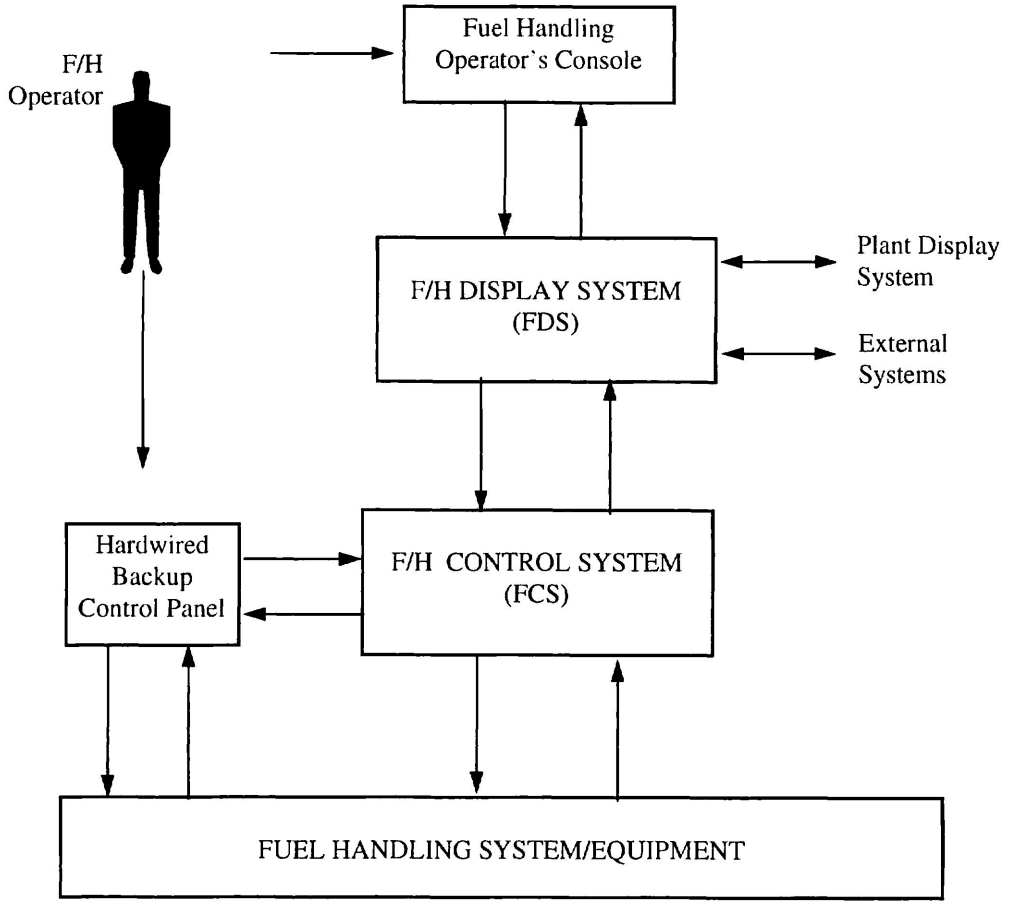

Figure 1 Block Diagram of the CANDU 9 Fuel Handling Control/Display System

The fuel handling display system provides the operator interface via the F/H operator's console located in the main control room. All normal, abnormal and emergency F/H operations are carried out from the F/H operator's console.

A hardwired backup control panel with limited functionality is also provided to put the fuel handling equipment into a safe state in case of failure of the fuel handling control/display system. The control/monitoring/annunciation functions at this control panel are directly hardwired to the field devices.

THE FUEL HANDLING CONTROL SYSTEM (FCS)

The fuel handling distributed control system is the main component of the overall fuel handling control system. Other components include the Hardwired Protective Interlock System and the Seismic Trip System. The Hardwired Protective Interlock system is provided to:

- minimise damage to the F/H equipment and fuel bundles due to inadvertent operation,
- minimise the possibility of damage to safety related systems such as Heat Transport System (HTS) and Containment which interface with the F/H System.

The Seismic Trip System is provided to avoid the possibility of inadvertent operation of the fuel handling equipment during a seismic activity. It

- continuously monitors the acceleration of the reactor building to detect the onset of an earthquake, and
- interrupts power to predefined drives after detecting the onset of an earthquake so that they fail safe before the DBE occurs.

Design Features of the F/H DCS

The design features of the CANDU 9 fuel handling control systems are:

- substantial reduction of control components (compared to CANDU 6) leading to improved reliability and reduced maintenance and construction costs.
- reduction of different types of hardware and software platforms in the plant to reduce the cost of inventory and maintenance (e.g., by incorporating similar hardware/software used in other parts of the CANDU 9 plant).
- use of proven and commercially available hardware and software components.
- increased level of automation and operability (e.g., with more automated sequences), building on the existing CANDU design features to free operations staff from tedious tasks, and thereby reduce the frequency and likelihood of operator error.
- improvement on the overall safety of the F/H System.
- use of high level programming languages for easier software development and maintenance.

Control System Configuration

The CANDU 9 F/H system is physically divided into two partitions (one for reactor side A and the other for reactor side C). The two partitions are almost identical and are

controlled by two dedicated DCS's. Each partition is further decomposed/grouped into 6 subsystems:

- Fuelling machine carriage
- Fuelling machine head
- Fuelling machine fluid system
- New fuel transfer system
- Irradiated fuel transfer system
- Shielding doors and other miscellaneous systems

Supervisory controls for each reactor side are handled by a separate Sequential Control Systems (SCS). The SCS manages all F/H operations. The control function provides a hierarchical structure of jobs, sequences and steps as described below:

- Job: A set of sequences
- Sequence: A set of steps
- Step: A set of operations comprising commands and feedback checks

Limited communications are provided between the two sequential controllers for coordination of fuel handling operations. Sequential controls can be executed in any of the following modes:

- Automatic mode (for normal operation)
- Semi-automatic mode
- Manual mode

Each F/H subsystem is controlled by dedicated subsystem and device controllers. The CANDU 9 F/H design makes extensive use of electrical drives with brushless DC servo motors for actuating mechanisms. These motors will be controlled by dedicated closed loop motion controllers. The subsystem controllers of each side are connected by a network to provide distributed control functionality and transfer data to FDS which provides operator interface functions. Dual redundant network links are provided with on-line communication error checks. The block diagram of the F/H DCS is shown in Figure 2.

Redundant subsystem controllers, motion controllers, interface modules and drives are provided where necessary for operational reasons (e.g., to retrieve the fuelling machine without shutting down the reactor, should the fuelling machine get stuck in the reactor

vault due to a motor failure). In such cases, full redundancy is provided for the control loop (e.g., from motion controller to the motor) for that mechanism.

Other control system functions include computational functions and monitoring functions. Extensive system monitoring and diagnostic facilities are provided to minimize system down time.

The FCS is designed to fail safe to the extent practicable. In case of system faults, the outputs of the F/H DCS, hardwired interlock system and the seismic trip system will fail to a safe state.

The FCS provides an Engineering Work Station for the purposes of programming/ configuration, control, annunciation, calibration functions, debugging/trouble shooting, simulation, etc.

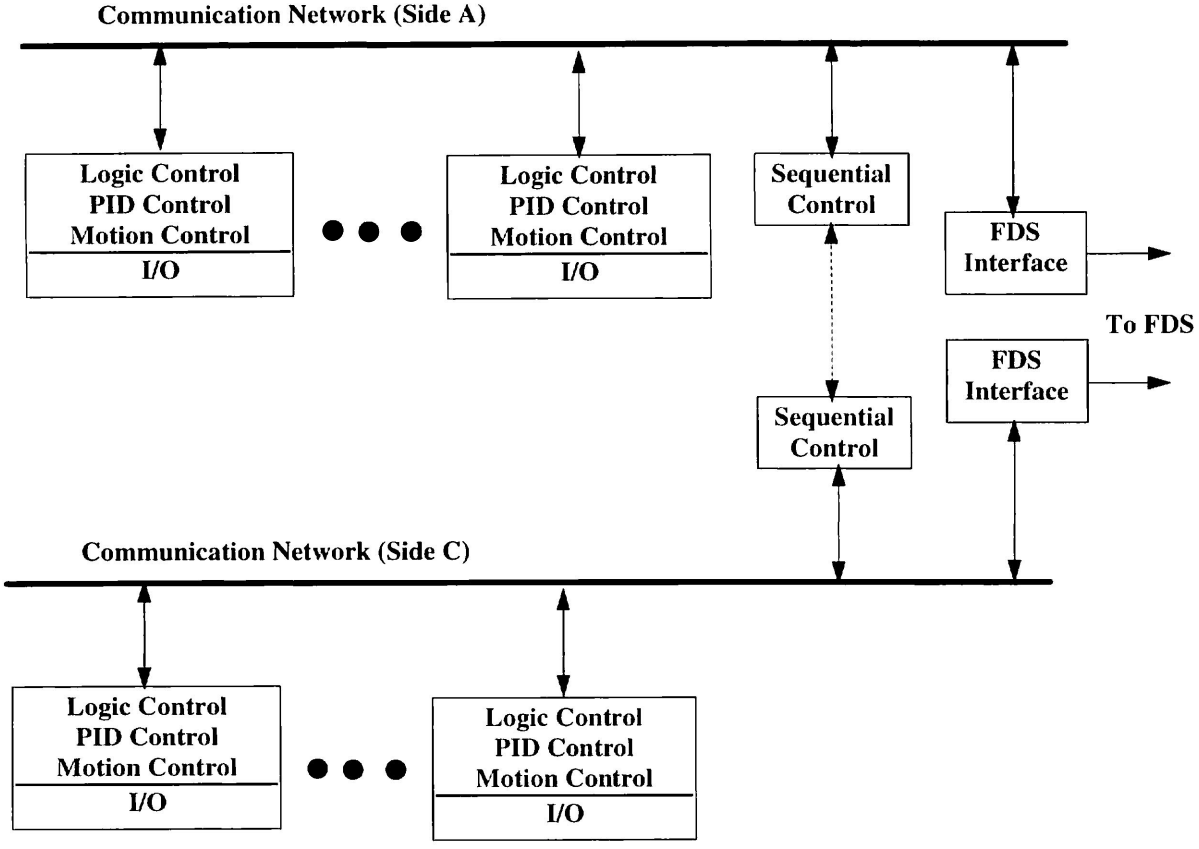

Figure 2 Configuration of the CANDU 9 F/H DCS

THE FUEL HANDLING DISPLAY SYSTEM (FDS)

As a subsystem of the plant display system (PDS), the FDS is functionally and operationally independent of the F/H DCS. It provides a user-friendly operator console, F/H DCS interface and other data processing nodes for display, annunciation, data logging and reporting, diagnosis, etc.

Design Features of the FDS

The design of the CANDU 9 fuel handling display system is based on the latest available technology utilizing standard off-the-shelf hardware and software components to the maximum possible extent. The system design has the following design features:

- Reduction in the instrumentation and control equipment count on the hardwired panels leading to improved reliability and reduction in maintenance and construction costs by providing a flexible, versatile and user friendly display system.
- Reduction in the cost of inventory and maintenance by minimising the different types of hardware and software platforms in the plant.
- Improved F/H operation/maintenance flexibility by providing full functional independence for the F/H System from the rest of the plant subsystems.
- Improved operability by providing a flexible navigation system. The displays are predominantly graphical (animated where necessary) and require minimal data entry by the operators. The F/H operator has quick access to all the F/H information through a context sensitive display navigation system
- Improvement in safety of the F/H system by providing an information and data communications system that facilitates an awareness of the F/H operational state and provides better detection and diagnosis of faults.
- Use of advanced programming tools for easier software development and maintenance.
- Incorporation of strict human factors guidelines which provides a user friendly and task oriented operational environment.
- Adoption of advanced features such as system diagnostic and operator guidance.

Even though the CANDU 9 FDS is functionally independent, it is part of the overall plant-wide information system which is designed to:

- provide improved reliability and availability with dual redundant computer system configuration,
- use currently available and proven off-the-shelve hardware and software meeting the international open systems standards, and

- use advanced programming and display design tools to improve design and development efficiency and facilitate simpler system maintenance.

Display System Configuration

The CANDU 9 FDS system architecture is based on a Local Area Network (LAN) with distributed functionality. A dedicated communication interface is provided for communications with the F/H DCS. A dedicated F/H control console is provided for F/H operator interface. Other nodes are provided for data processing, alarm processing, maintenance facility, and other data interfaces. The FDS provides a real time database which is accessed for monitoring, checking, display and annunciation much more extensively than was possible in previous designs. Data processing uses this real time database and involves:

- signal processing,
- monitoring/calculations,
- alarm functions,
- Logging, and historical data storage and retrieval, and
- report generation

A conceptual block diagram of the fuel handling display system is shown in Figure 3.

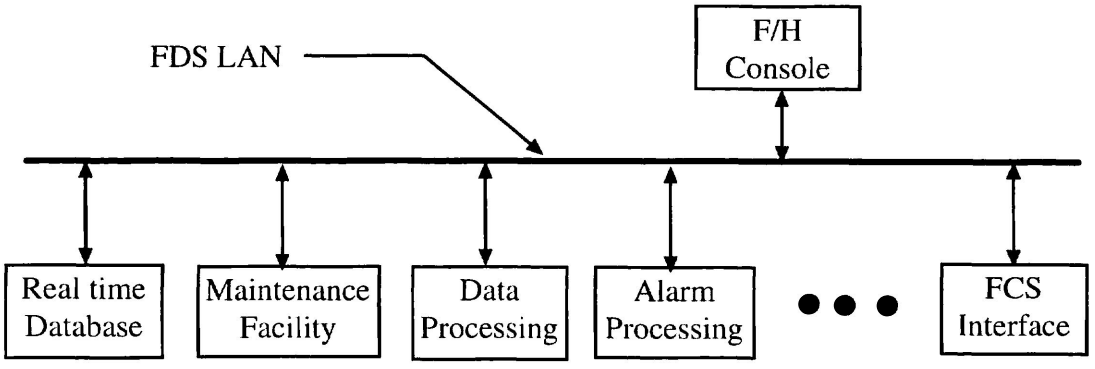

Figure 3 Conceptual Block Diagram of the F/H Display System

The FDS largely unloads the F/H operator from routine parameter cross comparisons and panel checks, and diverse parameters can be automatically compared on a low frequency background basis. Combining the real time database with powerful computer processing provides a unique, reliable and user friendly annunciation system which facilitates the

recognition of events, F/H system state and required corrective actions by the F/H operator.

The maintenance facility serves as a technical interface to the FDS and is used to configure or modify displays, create new or modify existing database entries, create new or modify existing report templates, etc.

The F/H Operator's Console

The F/H operator's console is located in the main control room. It provides the primary interface to the F/H operator for information display and control functions. The console consists of 4 CRTs and a set of data entry devices (e.g., keyboards) and pointing/ navigating devices (e.g., mice). All normal and emergency control and monitoring operations can be performed from this console. Two of the 4 CRTs are primarily dedicated for reactor side A (one for control and the other for information display purposes). The other two CRTs are assigned for reactor side C in a similar manner. Two dedicated alarm display CRTs (one for each side of the F/H system) are provided for the F/H alarm displays for both reactor sides. The FDS also provides facilities for printing hard copies of any F/H display screen, alarm messages, events, reports and logs, etc.

A preiminary wireframe model of the console is shown in Figure 4.

Control CRT

The control CRT provides the following functions:

- Automatic and semi-automatic control of the F/H operations,
- Manual control of individual drives/devices,
- F/H system start-up and shut-down, and
- Calibration of F/H mechanisms

Data Display CRT

The data display CRT provides the following functions:

- F/H system overview information,
- Display of flow sheets,
- Animated display of F/H operations,
- I/O, drive and equipment data, and
- Historical data

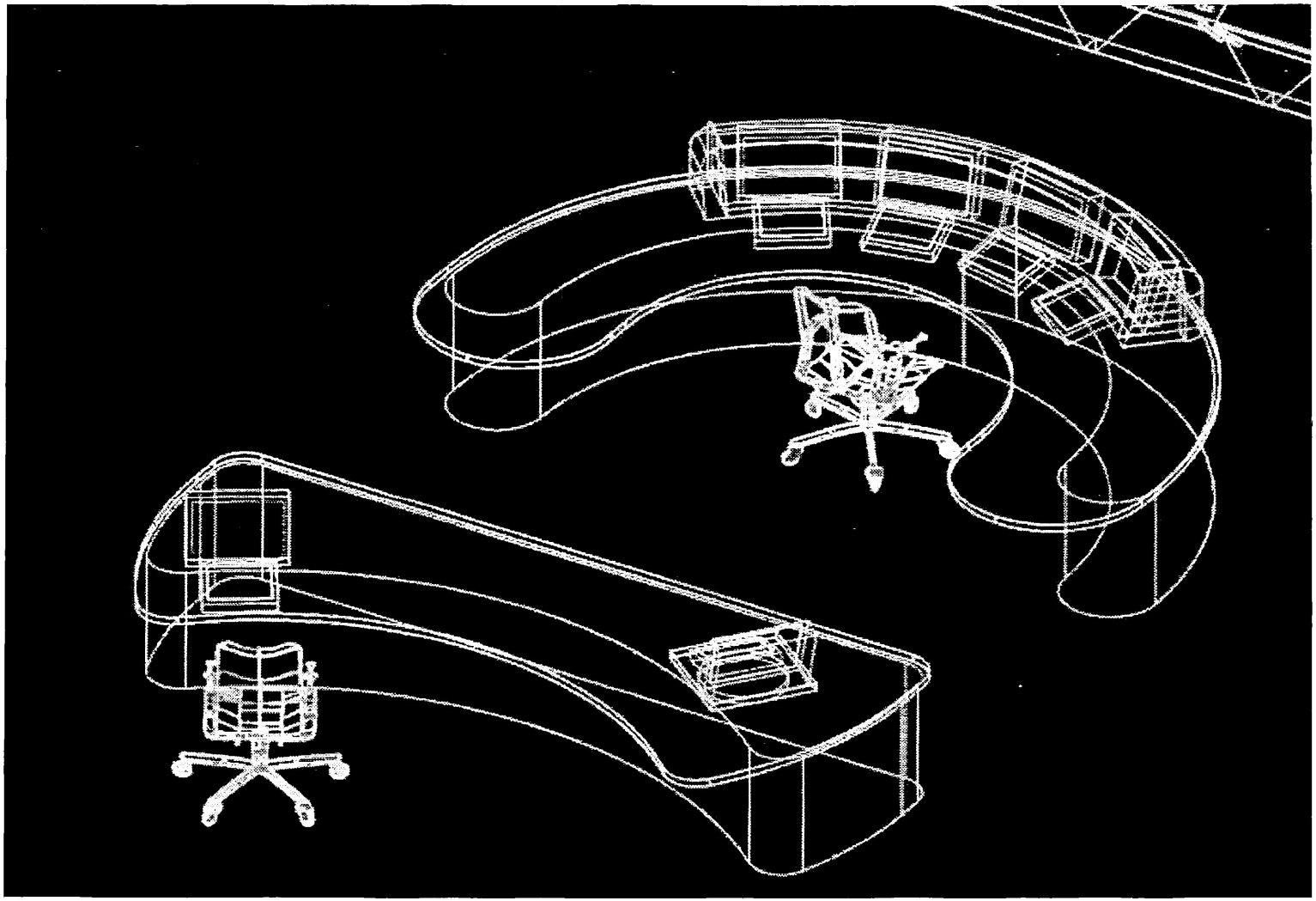

Figure 4 Preliminary wireframe model of the CANDU 9 F/H Control Console

Control Operations

Control displays are designed to facilitate full auto, semi-auto and manual control operations for each of the jobs, sequences and drives. The control operations generally involve merely selecting the required operations, control modes, and set points from the pop-up control windows. The operator is rarely required to input any data or commands through the data input device. Control command validation is carried out before any command is sent to the F/H control system.

Display Capability

Displays are graphics oriented to facilitate user friendly operator interactions. Displays are arranged in a logical and hierarchical structure for easy navigation through the system to help the operator obtain correct and timely information. The displays are windows based and are designed on the basis of function analysis. Both information oriented and task oriented displays are provided with fast navigation techniques such as context-sensitive navigation, direct access and programmable function keys, etc. The operational status of the F/H system and messages to the operator are shown in simple English text and graphics. The following type of displays are provided:

- Annunciation and event displays,
- System alarm summaries,
- Menus,
- System and subsystem overviews,
- System status displays,
- F/H process displays,
- Analogue/digital trends (current and historical),
- Equipment displays
- Animated F/H operations,
- Control displays,
- Mechanism calibration displays,
- Select alternate device displays (for redundant resolvers, potentiometers, motors, etc..).
- Tool/plugs inventory displays
- Fuel bundle inventory displays
- Access Control displays
- Dynamic alpha-numeric displays

- I/O Point data
- Bar charts
- Plant/reactor status displays
- Platform/communication status/health displays

The flexible navigation system allows control and information displays to be accessed in a simple, direct, convenient and logical manner by operations staff.

In addition, real time video from CCTVs is provided in a separate window on the display CRT. F/H operation procedures are also provided on-line for the F/H operator.

Other functions provides by the FDS includes fuel bundle tracking, selected channel verification, channel identification and channel refuelling history.

The FDS also provides external computer interfaces for fuel management data, work order information, and F/H data to other station computer system.

CONCLUSIONS

The CANDU 9 fuel handling control system will provide fuel handling operations with the means to achieve improved operability and flexibility through a combination of enhanced design features and a systematic design incorporating human factors engineering and operational feedback. The modern DCS dedicated for the fuel handling control functions provides powerful and distributed control/processing capability with extensive system monitoring and diagnostic facilities to minimize system down time. The state-of-the-art fuel handling display system provides a flexible navigation system which allows custom information displays to be accessed in a simple, direct, convenient and logical manner by operations staff. The separation of the fuel handling display system from the fuel handling control system allows hardware/software changes to one system to be implemented without causing any impact on the other system. The CANDU 9 fuel handling display and control systems can be adapted to other new CANDU designs. Scaled down versions can be retrofitted to existing stations.