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ÉNERGIE ATOMIQUE DU CANADA LIMITÉE

INTEGRATED CONTROL CENTRE CONCEPTS FOR CANDU POWER PLANTS

CONCEPTS DE CENTRE DE COMMANDE INTÉGRÉ APPLIQUÉS AUX CENTRALES NUCLÉAIRES CANDU

L.R. LUPTON, E.C. DAVEY, P.A. LAPOINTE and R.R. SHAH

Presented at: American Nuclear Society Topical Meeting on
"Advances in Human Factors Research on Man-Computer Interactions: Nuclear and Beyond",
Nashville, Tennessee, 1990 June 10-14

Chalk River Nuclear Laboratories

Laboratoires nucléaires de Chalk River

Chalk River, Ontario K0J 1J0

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RÉSUMÉ

La taille et la complexité des centrales nucléaires ont augmenté considérablement au cours des 20 dernières années. Tout le monde s'entend pour dire que la sûreté des centrales et la production d'électricité peuvent être améliorées si on offre un plus grand soutien à l'exploitation sans surcharger l'opérateur d'informations inutiles. Les progrès récents en matière de techniques informatiques permettrent de mettre sur pied des systèmes de soutien à l'opérateur très différents de ceux fondés sur les techniques classiques utilisées actuellement dans les salles de commande des centrales. En particulier, l'intelligence artificielle et les technologies s'y rapportant joueront un rôle très important dans la création de nouvelles méthodes de présentation et de traitement de l'information. Ces techniques doivent être intégrées à la philosophie globale de gestion et de commande de la centrale et ne pas être considérées comme des moyens d'adoption de solutions ponctuelles. La philosophie de notre méthode est expliquée dans la présente communication. Les sytèmes de soutien à l'opérateur s'intégreront dans la philosophie globale de commande en jouant un rôle complémentaire à celui de l'opérateur. On décrit quatre systèmes de soutien; chacun est un prototype d'un système que l'on envisage d'utiliser dans la salle de commande du CANDU 3.

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ABSTRACT

The size and complexity of nuclear power plants has increased significantly in the last 20 years. There is general agreement that plant safety and power production can be enhanced if more operational support can be provided without overloading the operator with unnecessary information. Recent advances in computer technology provide opportunities for implementing operator support systems that are significantly different from the ones based on the more conventional technologies used in plant control rooms. In particular, artificial intelligence and related technologies will play a major role in the development of innovative methods for information processing and presentation. These technologies must be integrated into the overall management and control philosophy of the plant and not be treated as vehicles to implement point solutions. The underlying philosophy behind our approach is discussed in this paper. Operator support systems will integrate into the overall control philosophy by complementing the operator. Four support systems are described; each is a prototype of a system being considered for the CANDU 3 control centre.

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1. INTRODUCTION

The effect of operator errors on plant safety and operation has been discussed extensively over the past ten years [1,2]. There is general agreement that plant safety and performance can be enhanced if more operational support can be provided without overloading the operator with unnecessary information.

Recent advances in computer technology provide opportunities for implementing operator support systems that are significantly different from the ones based on the more conventional technologies used in plant control rooms. In particular, artificial intelligence (AI) and related technologies will play a major role in the development of innovative methods for information processing and presentation. However, because significantly new approaches and technologies are involved, the solutions will have to evolve as these technologies mature and gain acceptance in the control centre environment. Operator support systems will be integrated into the control centre of CANDU* 3 nuclear power plants [3] over the next 5 to 20 years.

Atomic Energy of Canada Limited (AECL) is developing a framework on which the newer approaches to operator support systems will be implemented. These systems must be integrated into the overall management and control philosophy of the plant and not be treated as point solutions. This paper summarizes the underlying philosophy behind our approach [4], and describes specific operator support systems being developed as prototypes for gaining experience and building a level of confidence and acceptance with the new technologies.

2. UNDERLYING PHILOSOPHY

The development of operator support systems presents designers with the following issues:

- the balance between power plant performance and safety goals,
- the balance between manual and automatic control (function allocation), and
- the inclusion of human factors (psychology, anthropometrics and task analysis), including human reliability.

We are developing new control centre concepts for CANDU, incorporating such advanced technologies as AI and expert systems, that will maximize the strengths of both the human and the machine during normal and abnormal operating conditions. The key thrusts of this approach are:

- a definition of the levels of automation,
- a comprehensive decision-making model,
- design of operator support systems using the application of human behaviour and reliability considerations, and
- presentation of information in the context of a plant situation or condition.

2.1 Levels of Automation

We have re-examined the generalized control problem and derived a hierarchy of activities [5] which parallels much of the structure of human decision-making behaviour (skill-based, rule-based and knowledge-based) defined by Rasmussen [6], allowing us to better define the man-machine interface.

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* CANDU: CANada Deuterium Uranium. Registered Trademark.

Plant activities that involve the performance of knowledge-based tasks, such as planning, scheduling and review of operations, interpreting situations and devising new procedures, are defined as "creative" and require the operator to be a "situation manager" (see Table 1). When the response to a particular situation must be completely predetermined, implementation should be in hardware, and is referred to as "hard control". When judgement requires the human to remain in the control and decision loop, control tasks should be shared between the machine and the human, and is called "soft control". We intend to implement operator support systems that will assist the operator to be the "situation manager" and to carry out the "soft control".

Table 1: Comparison of Levels of Automation

Decision-Making Behaviour	Characteristic	Definition of Functions Assigned to Operator	Definition of Functions Assigned to Machine	Responsibility for Action
Knowledge-Based	Creative Thought	Creative/Situation Management	Operator Support System	Operator
Rule-Based	Predetermined Response	Soft Control	Operator Support System	Designer/ Operator
Skill-Based	Automatic/ Conditioned Response	Hard Control	Hard Control	Designer

2.2 Decision-Making Model

Machine assistance can be introduced at various places in the information processing and control loop. We have examined the decision-making sequence to define logical communication points between the human and the machine.

First it was necessary to evaluate how information is used for control decision-making [5-10]. We have defined a five-step sequence of discrete activities, each with unique requirements and characteristics:

i) Acquire situation data,
ii) Perceive problem(s),
iii) Plan corrective action,
iv) Convert plan into control actions, and
v) Perform control actions.

The basic sequence forms a framework that can provide strategies for combining manual control, automatic control and management functions to treat the full range of control issues from single parameter control to the control of a complete plant.

2.3 Context-Sensitive Information

The CANDU 3 plant incorporates data highways and distributed control for all control functions. This distributed system architecture enables the adoption of the "soft" control room concept (also referred to as cockpit-type control [11]), where cathode ray tubes (CRTs) are used for presentation of plant information and for executing control operations. This concept can present the operator with information most relevant to the task in hand. The remaining plant data, formerly displayed on control-room panels, are available on demand. Relevance implies there are contexts that change with operating circumstances. By applying this concept throughout the design of the plant, including the operator support systems, we ensure the operator has access to the correct information within the context of the tasks to be performed to achieve the desired performance and safety goals.

3. OPERATOR SUPPORT SYSTEMS

Several new operator support systems are being considered for the CANDU 3 control centre. They have to be proven in the control centre environment, and therefore we are developing prototypes to gain experience in applying them. The prototypes, described below, will be evaluated by operators in real plant environments, or using simulators, to obtain operational feedback and to gain acceptance of the new approaches.

3.1 The Operator Companion

The Operator Companion is conceived as a family of expert systems and other advanced computing systems that will address the key plant functions of plant information access and display, on-line advice and diagnosis, alarm annunciation, and interactive operating procedures. Plant operations staff have identified the monitoring of plant configuration and equipment status, and the on-line detection and diagnosis of system faults, as applications that can yield the most immediate benefits. Functional requirements for each of these two areas have been developed [12].

A prototype Operator Companion has been implemented using workstations linked on a local area network (LAN). Three modules have been developed and are connected by the LAN: a plant database, an operator console and a subsystem advisor (see Figure 1). The requirements for the plant configuration and equipment status monitor led to the definition of a plant database and an operator console. The plant database acts as a central data repository for such data as measured values, component information (status, maintenance records, specifications, etc.), historical trends and shift logs.

The operator console serves as a high-level interface to selected data from the plant database, and alerts the operator to parameter changes (see Figure 2). It also serves as an interface to the subsystem advisor modules.

The requirements for on-line fault detection and diagnosis led to the need for subsystem advisors dedicated to specific subsystems of the plant. These advisors, based on advanced computer technology, such as expert systems, communicate with the operations staff through a message facility linked to the operator consoles or through more conventional alarm displays. For the prototype, a diagnostic knowledge base has been developed that monitors system parameters in the central plant database. Diagnostic messages generated by the advisor are dropped into a 'mail box' in the central database, where their presence is detected and annunciated to the operations staff on the operator console.

3.2 On-Line Fault Diagnostic Systems

The failure of system operation, as designed, eventually precipitates a number of alarms that have to be interpreted and the root cause of the failure diagnosed. With 6000 measured and calculated variables in a CANDU plant, there are operational circumstances when an event can result in a flood of alarms. Such information overloads put severe demands on the operator, who must attempt to diagnose the fault and take timely and correct action.

We are developing prototype on-line diagnostic systems that will advise plant operators on root causes of alarms and give them a capability to predict potential failures. An early prototype has been developed for a small heat transfer circuit; it is based on a model representation using the qualitative physics of De Kleer and Brown [13], and first-principles diagnosis using constraint suspension [14]. Temporal information was integrated into the diagnosis using a type of directed graph to record event dependencies. This graph was used to dynamically alter the qualitative model to reflect changes in the system over time. Although not completely formal, our method has successfully integrated the time diagnostic information to identify the faulty components in several tests. The number of spurious candidates was low. More work is planned in the area of combining the qualities of this approach with conventional expert systems.

3.3 Computer-Assisted Procedures

The performance of the CANDU design will be enhanced through the use of a "soft" control interface in the control room, that integrates control execution, annunciation and information display. We are committed to providing a design that maximizes the strengths of the human and the machine during normal and abnormal operating conditions. One area for improvement is the use of computer-assisted procedures, especially during abnormal operating conditions. The intention is not to just computerize the procedures, i.e., have the procedures presented on CRTs in the same format as would be shown on paper, but rather to incorporate significant information processing and analysis capabilities to provide the operating staff with a tool that will truly assist them in plant monitoring and executing the procedures. Recent work by Electric Power Research Institute (EPRI) [15] confirms this approach.

For CANDU 3, we propose to:

- integrate all aspects of the decision-making model in the man-machine interface design,
- define the tasks to be performed by the computer and by the operator, based on a functional analysis of the plant (including task and job analysis) [16], and
- implement a 'procedure' in an environment that integrates annuncaition, event/symptom identification, information display and control execution.

We have developed a prototype computer-assisted Emergency Operating Procedure (EOP) based on the Point Lepreau Generating Station Loss of Instrument Air procedure (see Figure 3). The plant operators will be able to compare the performance of the computer-assisted procedure with the conventional paper-based procedure. This evaluation should provide valuable feedback for the designers and will allow the operators to experiment with the new technology.

3.4 Computer-Based Training System

An interactive computer-based training aid is being developed for operator training in emergency recognition and response to loss-of-coolant scenarios during refuelling operations for the NRU research reactor at the Chalk River Nuclear Laboratories.

The training aid incorporates both conceptual and functional training features. Conceptual training consists of sequenced presentations of text, graphics and animations to explain the fuelling-system configuration, operations, abnormal events and recovery procedures. This feature familiarizes the student with refuelling operations and establishes "mental models" for operational use in analyzing refuelling operations. Also, it characterizes the symptoms for specific loss-of-coolant events and relates recovery actions to specific operational objectives.

Functional training consists of an interactive simulation of refuelling operations presented on a multi-window CRT display (see Figure 4). Three simulation modes provide a graduated transition from an off-line, guided-walkthrough of recovery procedures to an unaided, real-time replication of loss-of-coolant events. This training aspect provides real-time procedural practice in event recognition and recovery, and a standardized means of evaluating student performance.

To obtain the detailed information for this training aid from both operational and training perspectives, a functional analysis of recovery procedures was performed at the beginning of the project, which provided a method for relating operational goals to recovery actions and identifying the subset of refuelling console instrumentation and controls required for event recognition and response training.

4. CONCLUSIONS

The size and complexity of nuclear power plants has increased significantly in the last 20 years. The continued advancement of computer technologies offers new opportunities for providing assistance to the operator at a time when human error is being increasingly recognized as a key component in industrial accidents.

The underlying philosophy leading to the integration of operator support systems in CANDU addressed the issues of the balance between performance and safety goals, the balance between manual and automatic control and the inclusion of human behaviour and reliability issues. Operator support systems will integrate into the overall control philosophy by complementing the operator.

Four prototype support systems have been described. Additional work is planned to gain experience, confidence and acceptance with these new systems incorporating advanced technologies.

5. ACKNOWLEDGEMENTS

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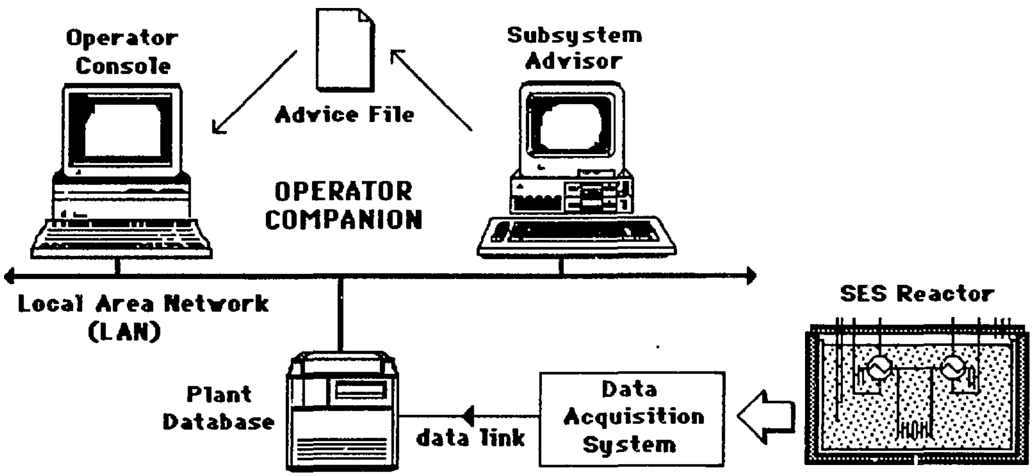

Figure 1. Overview of the prototype Operator Companion and the demonstration application.

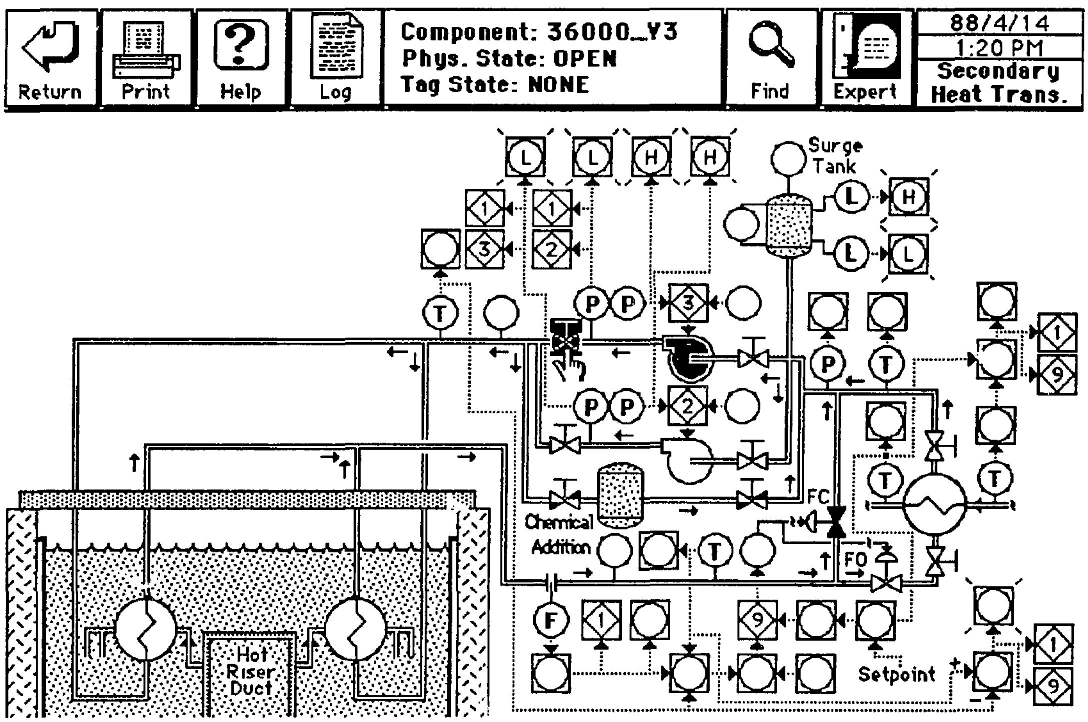

Figure 2. Process subsystem overview of the configuration and equipment status monitor console.

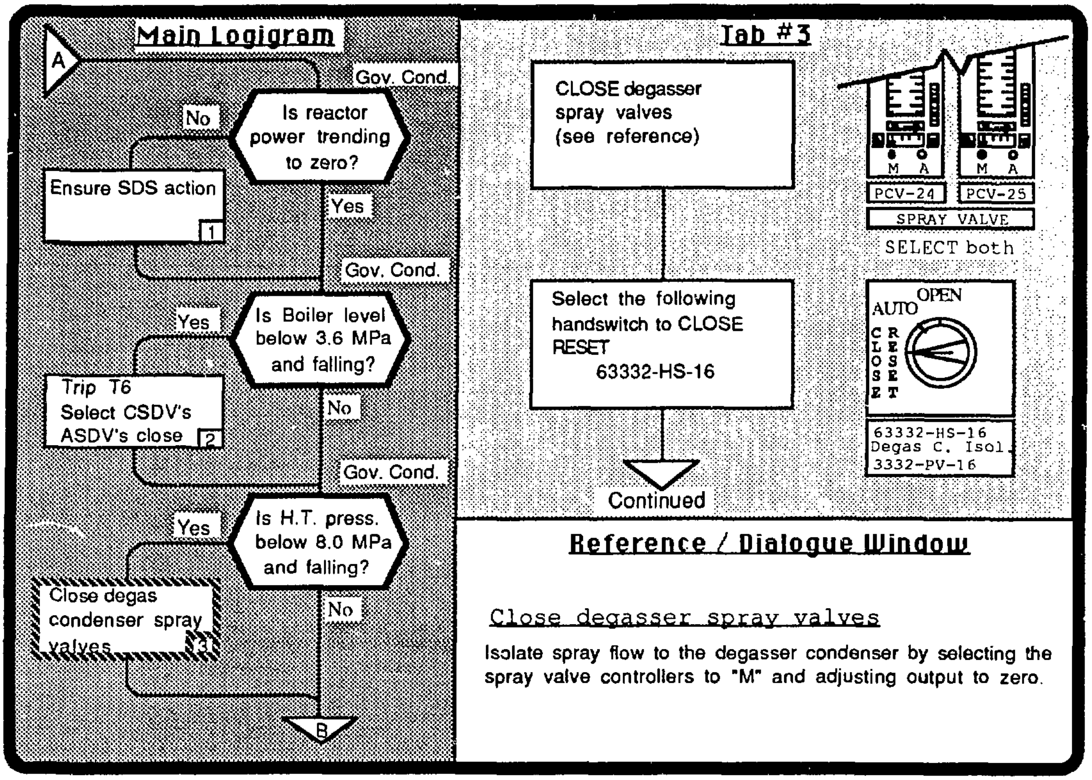

Figure 3. Prototype display for a computerized procedures system.

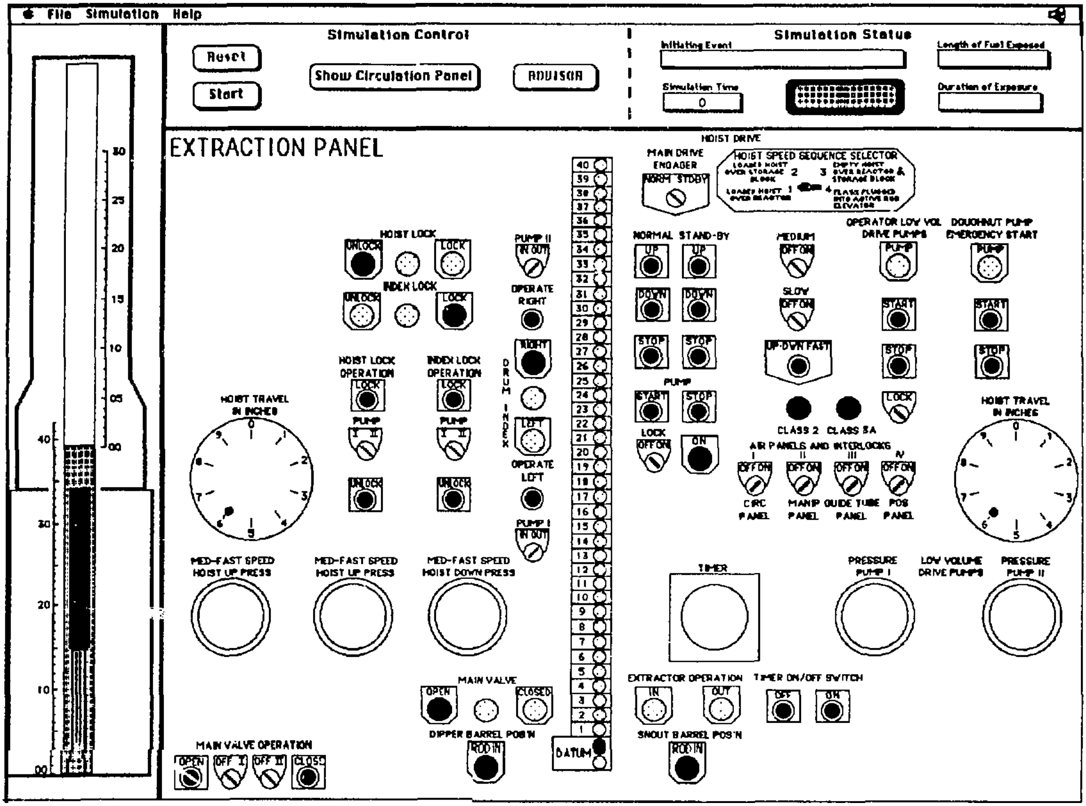

Figure 4. Panel mimic for a computer-based training system (screen dump from a 19" monitor).

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