# A FRAMEWORK FOR DEFINING THE FUNCTIONAL ROLE OF ANNUNCIATION

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*ABSTRACT*

*This paper describes a framework for examining annunciation and its use in a project to define the functional role for CANDU annunciation. This work was performed as part of a larger multi-year project to develop, evaluate and recommend an architecture for CANDU annunciation that better meets the information needs of plant staff under all plant operating regions. The first phase of the project, performed in 1991, has established an initial definition of the functional role for CANDU annunciation. Subsequent project phases will define options for solution for specific alarm functions at CANDU stations in areas where the present annunciation systems do not fully meet the needs of operations staff. This paper discusses background to the project, describes the place of annunciation in relation to other plant operator support and plant information functions, describes how the functional role was defined, and outlines the direction of further work.*

## INTRODUCTION

Operations staff in a nuclear power plant must assimilate and understand large amounts of information to control the plant safely and effectively. Over the past twenty-five years of nuclear plant operation, the amount of information annunciated to operations staff has increased significantly, due to:

- the increased size and complexity of newer power plants,
- the application of computer-based technologies that have increased the capabilities for data acquisition, processing and presentation, and
- the continued use of annunciation implementations that rely on annunciating the change in status of individual sensors, components and equipment.

While the amount of annunciated information has grown, the understanding of how to process and present this information to plant staff to best fit operational needs has not kept pace. This can result in a "flood" of annunciation messages during plant

upsets, with the consequence that it is difficult to identify the few annunciation messages of most importance for the situation, because they are mixed in with many other, less important messages.

The need to improve nuclear plant annunciation has been well recognized within Canada and internationally for many years.[1,2] Most recently, discussions by operations and design staff at the 1990 COG CANDU Computer Conference have reiterated that current CANDU annunciation implementations do not meet the needs of the operators for major events, and still require improvement.[3,4] A review[5] of the methods and techniques developed by international utilities and research organizations has identified a number of ways to implement annunciation improvements. However, their application will require careful integration with existing systems and plant practices, to ensure that the overall information needs of operations staff are met.

These review findings and discussions with operations and design staff have re-emphasized the importance of looking at annunciation from a user's perspective within the overall context of plant operation. We believe that such an approach will provide a sound basis on which to improve future annunciation implementations.

## ANNUNCIATION WITHIN THE PLANT ENVIRONMENT

The purpose of a nuclear power plant is to produce electric power safely and efficiently. The purposes of plant personnel and systems are to perform functions necessary to achieve the power production and safety goals. These functions are accomplished through the performance of tasks assigned to humans and machines. For most tasks, responsibilities are divided between humans and machines.

In current CANDU plants, annunciation is commonly viewed as a function that detects and alerts control room staff to deviations in plant parameters. These parameter changes are primarily defined as excursions away from the nominal values under full-power operation.

In practice, it is necessary for other plant staff (i.e., maintainers, field operators and system engineers) to be alerted to plant parameter changes to perform their normal tasks. In addition, it is necessary for plant staff to be alerted to plant parameter changes when the plant is in states other than full-power operation. Thus, the need of all operational staff to be alerted to plant parameter deviations for all plant situations should be considered when examining the role of annunciation.

Definition of Annunciation

In our work, annunciation is a plant function that detects and may predict the occurrence of predefined plant transitions, and provides direct attention to:

- alert users that a process parameter or system condition is abnormal for the current plant operating region and state, and

- point users to additional plant information to understand and respond to the transition.

The "alerting" role redirects a user's attention by the way in which the specific plant information annunciated is conveyed, and by the perceived importance of the message content. The "pointing" role supports users by leading them to appropriate plant information for the situation (e.g., information to identify, assist, guide or confirm) by primarily the meaning of the message.

The ability to predict the occurrence of plant transitions has been included in the above definition, because advance warning of the potential changes of plant parameters provides operations staff with additional time to respond to the situation to avoid loss of production or challenges to plant safety.

Relationship of Annunciation Functions and Systems

The relationship of annunciation functions and systems that implement annunciation features is shown conceptually in Figure 1. We have distinguished between the view of annunciation as a function and its implementation as a system. In general, a system can be considered a specific machine implementation of a plant function.

As Figure 1 indicates, the two aspects of the annunciation function definition may be implemented by means of several systems. In practice, the "alert" function has been addressed primarily by the annunciation system, though some "alert" function aspects may be more appropriately implemented in the future as a part of other plant information support systems, to best satisfy user needs. Likewise, the "pointing" or "support" function may be partitioned and implemented by means of several systems.

Categories of Annunciation Messages

The information contained in annunciation messages represents a subset of all the plant information available to operations staff. The importance of bringing a specific piece of information to the attention of operations staff is dependent on the operational context of the plant. For this project, three categories of

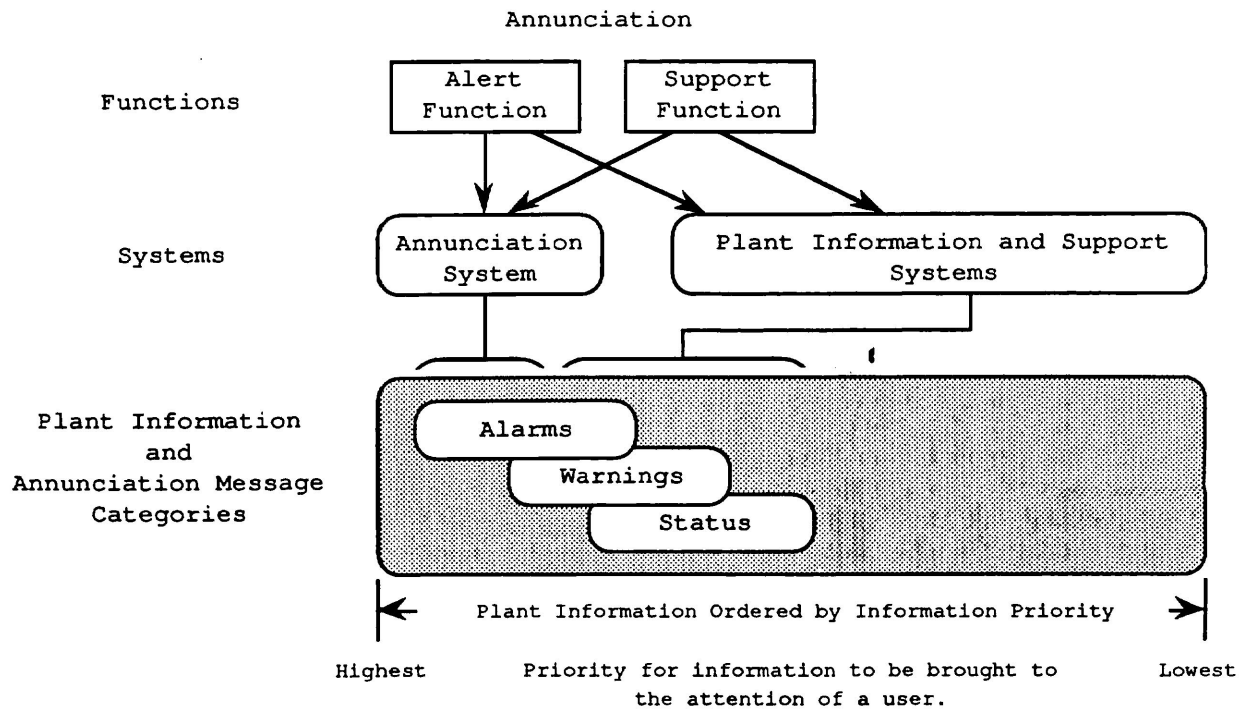


**Figure 1: The relationship of annunciation functions, systems and messages.**

annunciation message have been defined based on message importance:

- An *alarm* message indicates plant changes that have adversely affected plant operational goals. Operators should immediately attend to the conditions annunciated by the alarm message, and begin undertaking a course of action to stabilize the plant.

- A *warning* message provides advance notice of plant conditions that, if left unaddressed, would adversely affect plant operational goals. Operators do not necessarily need to immediately attend to the conditions annunciated by warning messages, but they should plan to respond to the situation before operational goals are adversely affected.

- A *status* message indicates a change in status of equipment, systems or processes, or the completion of actions supportive of the successful achievement of plant operational goals. Operators do not need to immediately attend or respond to the conditions annunciated by status messages; they may respond at their discretion.

The relative position of these three annunciation message classes within the space of all plant information is shown in Figure 1. In this figure, plant information has been ordered according to the priority that is dependent on the importance of information

for operations staff, and as the plant condition changes, the priority may change.

In current CANDU practice, almost all annunciation messages originate and are presented via the annunciation system. However, in future implementations, annunciation messages of differing priorities could be generated and presented to users by different systems. For example, the annunciation system could be limited to present only alarms and some warnings to help focus a user's attention on the most important information in an event.

The allocation of a specific annunciation message to one of the three message categories depends on the operational context, and is based on several factors:

- the degree to which the information indicates a challenge to human and plant safety,
- the degree to which the information indicates full power production may be disrupted,
- the degree to which the information indicates plant economics may be adversely affected (i.e., increase in production, maintenance or equipment replacement costs),
- the degree to which the information indicates a challenge to regulatory rules or utility operating policies and procedures,
- the size of the plant disturbance indicated by the information (i.e., a component malfunction versus a major process disturbance, or a single parameter being abnormal versus a major plant emergency),
- the availability of time and resources (i.e., human or machine) to address the situation indicated by the information,
- the relevance of the information to the current plant operational state (e.g., full power, shutdown, fuelling),
- the relevance of the information to the current operations staff tasks,
- the purpose for annunciating the information (i.e., to alert versus assist, identify, guide or confirm),
- the intended user of the information (e.g., operators, shift supervisors, system engineers or maintainers), and
- the degree to which the information is already available and visible to users in plant human-machine interfaces.

Task Execution

A decision-making model was used to provide a framework for examining operational tasks and annunciation functions. For this project, a model developed by Rasmussen[6] was used. This model is particularly appropriate because it can be applied to process control applications, and can represent multiple decision-making behaviours.

The model represents decision-making and task execution by eight action steps: detect, observe, identify, interpret, evaluate, define task, select actions and execute. In the performance of a task, users do not necessarily spend equivalent effort for each action or perform all eight steps of the model in sequence. Depending on their experience, the task situation, and difficulty, more effort may be spent on some actions than others, and some actions may be skipped.

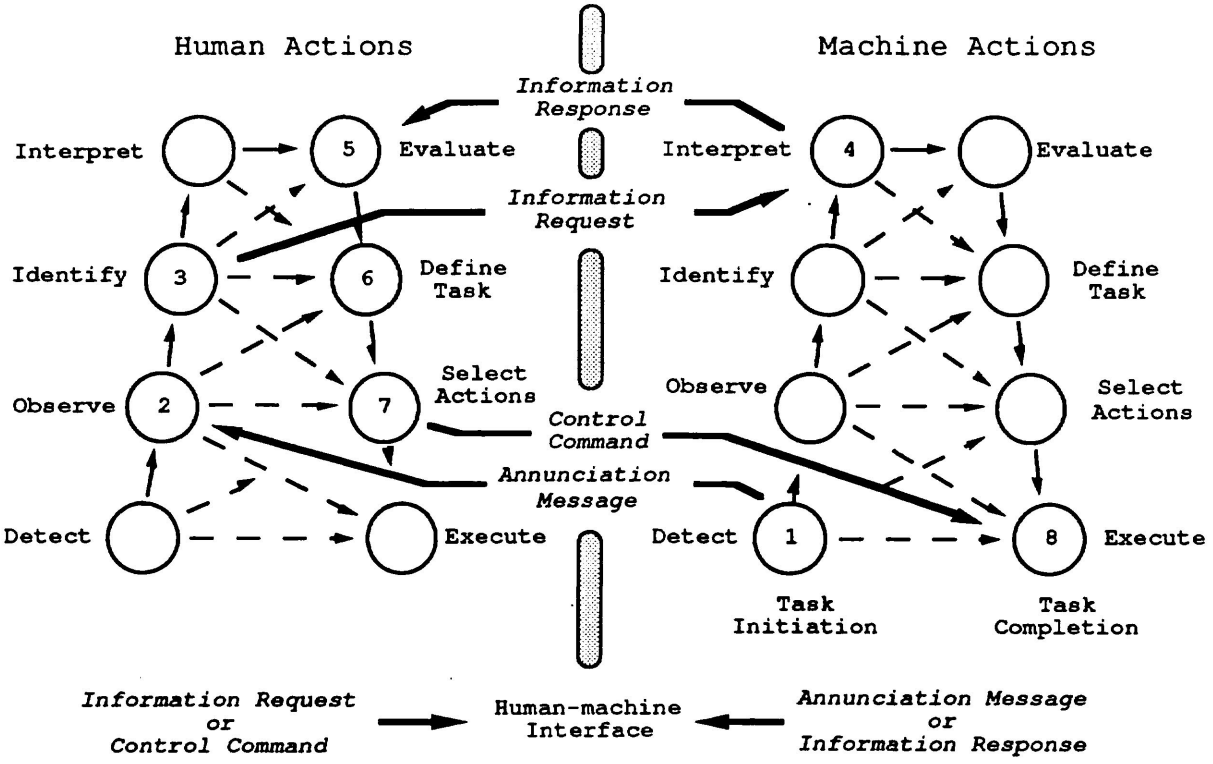


Figure 2: Task execution with action shared between human and machine.

In a nuclear power plant, many plant tasks are performed through a sharing of task actions by humans and machines. The decision-making model can be applied as a framework to represent the sharing of task actions and to illustrate key communication between human and machine to support task execution. Figure 2 shows task actions on two decision-making model frameworks: human actions are on the left and machine actions are on the right. Information that must be transmitted between the human and machine

to support the transfer of task execution responsibility is shown by arrows that pass through the human-machine interface between the decision-making frameworks.

An example execution sequence for the eight task decision-making actions in Figure 2 is shown using numerical labels. The actions of observe, identify, evaluate, define task and select actions are performed by the human, while the actions of detect, interpret and execute task are performed by the machine. In practice, the task execution and the supporting human and machine communication are more complex than this example indicates. For example, the performance of individual task actions may be shared, necessitating specific communication between the human and machine to support the completion of a single action. In some instances, the responsibilities for performing task actions for a specific task may change, depending on the operational circumstances. Finally, this model only indicates a portion of the information communicated through the human-machine interface from the machine to the human. The communications shown are only those that cue actions when a transfer of execution responsibility occurs between the human and machine, or vice versa. During all the task execution, machine-originated information is continually updated and presented in the interface for human use.

## OPERATIONS AND DESIGN EXPERIENCE WITH ANNUNCIATION

Canadian utilities and designers have over thirty years of operational experience with annunciation in CANDU nuclear power plants. The project team drew on this experience to obtain a broad understanding of how annunciation is currently used, to confirm successful aspects of current annunciation implementations, and to identify areas where improvements from an operational perspective were desirable. Knowledge of the capabilities and behaviours of humans to perform infomation processing and decision-making for process control tasks was used to guide the examination of operational experience.

Four CANDU generating stations were visited by the project team: Point Lepreau, Bruce A&B, Darlington and Pickering. From the discussions with operations and design groups, the following key points were identified. Annunciation should:

- support all plant operating regions and plant states,
- support all users,
- present annunciation information in several hierarchical levels,
- tailor messages for different plant conditions and task levels,

- provide predictive annunciation for early warning of major events,
- provide assistance to identify response procedures,
- provide better support for cause and root cause determination,
- apply the "Dark Panel" concept for all plant states, and
- provide support for commissioning, testing and preventative maintenance purposes.

## FRAMEWORK FOR EXAMINING ANNUNCIATION

A framework was developed to organize and classify annunciation-related issues and suggestions collected by the project team. This framework consists of four elements:

- *functions,* which specify the purpose of annunciation,
- *function allocation assignments,* which determine how much machine support is provided to users for annunciation functions,
- information *content,* which specifies the type of annunciation information presented to users through human-machine interfaces, and
- information *form,* which specifies the way annunciation information is conveyed to the users.

Annunciation can be defined in increasing levels of detail, beginning with the definition of functions and proceeding, in turn and iteratively, through the definition of function allocation assignments, content and form. The following subsections describe each element more fully.

### Functions

Functions specify the purpose of annunciation in support of operational tasks. They identify a purpose or goal and the collection of tasks for achieving the purpose or goal. They do not indicate how the implementation of the function is to be partitioned between humans and machines. Also, functions do not explicitly specify the information that needs to be communicated between humans and machines in support of operational tasks, or how such information should be best communicated.

Function Allocation Assignments

Function allocation assignments identify the preferred sharing of annunciation function responsibilities between humans and machines in support of a specific operational task. In practice, a number of assignment criteria can be used to determine function allocation assignments. However, to enhance overall performance, function allocation assignments are most appropriately determined by matching the task demands (i.e., actions and characteristics) for each operational task with the capabilities of humans and machines.

Task actions are the perceptual, cognitive and psychomotor activities that need to be performed to accomplish the task. Examples of generic task actions are detecting, observing, identifying, interpreting, evaluating, defining tasks, planning actions, and executing actions. Task characteristics are action or contextual attributes that describe distinguishing features of task performance. Examples of task characteristics for detecting are the accuracy required, explicitness of decision criteria, amount of signal change to detect, signal to noise ratios, and the number of signals to monitor.

The task demands of a function can be shared between humans and machines, depending on which resources are most suitable to address them. However, for a given function, there may be several acceptable ways of dividing function responsibilities between the human and machine, resulting in a range of complementary assignments.

Content

Content refers to the type of annunciation information presented to users through the human-machine interfaces in support of operational tasks. Annunciation information can be organized hierarchically by content categories (e.g., information on plant operational goals at the top and information on component functions at the bottom). Such an organization can help designers ensure that information presented in interfaces is in an appropriate context to support users in performing operational tasks. Two kinds of annunciation information are needed:

- information concerning the functional purpose (i.e., goal satisfaction criteria and means of achieving the task), and

- information concerning the situation and context (e.g., plant, process, system or component status) relevant to the task.

Past and current implementations of process control human-machine interfaces primarily provide information about the situation to users. Information about goals and the means to achieve them tends not to be explicitly presented in interfaces. Users recall

this information from memory or plant documentation (e.g., procedures) when performing operational tasks. The cognitive component of operator tasks could be simplified by having the information about goals and the means to achieve them explicitly represented in plant human-machine interfaces.[6]

Form

Form specifies the preferred visual or auditory manner in which annunciation information is conveyed to users through the plant human-machine interfaces. The objective is to specify information forms that communicate task-related information to users in manners that match the way humans use information for cognitive reasoning and decision-making. Information that is communicated in a less suitable form for task use will impose an additional cognitive load on users, as the information is converted to the form required for the reasoning or decision-making behaviour required for the task. Thus, form can be determined from an examination of the cognitive information processing and decision-making behaviours employed by users in performing operational tasks. Form does not necessarily specify the type of media to be used.

## PROJECT FINDINGS

### Scope and Approach

In this first project phase, the functional role definition was limited to:

- the identification of an initial set of annunciation functions, and
- the association of these annunciation functions with operational tasks.

To complete this initial role definition, three activities were performed. First, a set of operational tasks performed by different plant staff that involved annunciation were identified and described, based on operations and design documentation and experience. These tasks characterized the scenarios where annunciation was used.

Second, a set of annunciation functions were identified, based on operations and design documentation and experience. These functions comprised the initial definition of annunciation functions for the functional role.

Third, the operational tasks were examined to identify the annunciation functions that were required to support task execution. This resulted in a set of associations that link annunciation functions to operational tasks.

Operational Tasks

Twenty-seven operational tasks that involve the use of annunciation were identified and described. Twenty-four tasks were found to be performed on an unscheduled basis (i.e., tasks performed in response to an unplanned event or malfunction). Three tasks were found to be performed on a scheduled basis (e.g., the routine testing of systems, where the annunciation system is used to confirm test responses).

Three sets of factors (i.e., plant operating regions, users and decision-making phases) were used to characterize and classify tasks.

Plant Operating Regions. Plant operating regions are a classification of plant operation by the status of a set of critical safety parameters.[7] The status of critical safety parameters in CANDU plants is representative of the adequacy of fuel cooling, and the integrity of the heat transport system and containment. Four plant operating regions (i.e., Normal, Abnormal, Upset and Emergency) have been defined.

CANDU plants are characterized by long periods of power production where safety barriers are only rarely challenged (i.e., operation within the Normal operating region with brief durations within the Abnormal operating region). Thus, a large emphasis of annunciation is to alert and support operations staff in response to plant deviations that affect power production but do not necessarily challenge safety barriers.

Users. Plant operation involves the interaction and cooperation of diverse groups with unique job responsibilities. Discussions with operations staff identified the following four representative user groups:

- first operators and other licensed operators in the main control room,
- shift supervisors,
- system engineers and non-operational support staff, and
- maintainers and field operators.

Decision-making Phases. Operational tasks can be categorized into one of four decision-making phases, based on the predominant task emphasis of:

- Detection - user's attention is diverted towards a malfunction or event.

- Identification - analysis is performed to identify the current plant state, the cause and consequence of the malfunction.

- Planning - remedial actions by different groups are planned and decisions on the need for immediate or delayed recovery actions are made.

- Execution - planned actions are executed and monitored to confirm success.

Annunciation Functions

Twenty-five annunciation functions were identified (see Table 1); they form the initial definition of the functional role. These functions were grouped by predominant decision-making phase. Fifteen of the functions fall within the detection and identification decision-making phases.

Association of Functions with Tasks

In our analysis, tasks provide the situational context for how functions are applied; each task was found to be supported by several functions. For example, the task to identify critical safety functions that could be affected if a timely solution was not implemented is supported by four functions:

- alert the users of undesirable values and trending of critical safety parameters,

- alert the users of the impending loss of main plant functions,

- enhance the user's ability to understand process status even under fast transient situations, and

- assist the users to determine the system and equipment state.

## CONCLUSIONS AND CURRENT WORK

In this project phase, a framework has been developed for examining annunciation. We believe the use of this framework will lead to the development of an architecture for CANDU annunciation that better meets the information needs of the plant staff under all plant operating regions (the long-term objective of this R&D project). An initial definition of the functional role for CANDU annunciation (i.e., the first element of the framework) has been proposed that consists of 25 annunciation functions and their associations with the operational tasks. This definition supports

Table 1
Summary of Annunciation Functions

| No. | Function |
|---|---|
| | *Detection: Inform the users of deviations that have occurred in the plant that affect or could affect the plant operational goals:* |
| 1 | Direct the user's attention to system and equipment malfunctions. |
| 2 | Direct the user's attention to the occurrence of an event. |
| 3 | Assist users to track the execution of automatic actions. |
| 4 | Alert users of undesirable values and trending of Critical Safety Parameters. |
| 5 | Alert users of impending loss of production. |
| 6 | Alert users of impending loss of main plant functions. |
| 7 | Alert users of impending equipment and systems malfunctions. |
| | *Identification: Point users to information for evaluating the extent of the abnormality:* |
| 8 | Enhance the user's ability to understand the process status even under fast transient situations. |
| 9 | Support users in associating alarm signatures to events. |
| 10 | Indicate alarms caused by the malfunction of instrumentation. |
| 11 | Help identify the root cause of malfunctions. |
| 12 | Alert users of the unavailability of a dormant system. |
| 13 | Assist users to determine the system and equipment state. |
| 14 | Support users in handling conditions that exceed the design basis for the plant. |
| 15 | Support users in handling conditions that may result in failure to comply with operating licence regulations. |
| | *Planning: Point users to information for determining corrective actions:* |
| 16 | Predict the effects that the user's actions may have on safety and production aspects of the plant. |
| 17 | Guide users in the selection of applicable operating procedures. |
| 18 | Provide the means to summarize data to support communications between different users. |
| | *Execution: Assist in coordinating actions and confirm that actions have corrected the deviations:* |
| 19 | Support teamwork in execution of actions. |
| 20 | Alert users of off-normal selection of equipment. |
| 21 | Annunciate the success or failure of the operator's actions. |
| 22 | Record the sequence of events. |
| 23 | Support operators in post-accident situations. |
| 24 | Support users in testing systems and equipment. |
| 25 | Support commissioning of the systems. |

operational tasks for all plant operating regions, all users groups and in all decision-making phases, but with an emphasis on detection and identification phases.

Subsequent project phases will refine the definition, based on the development and evaluation of options for solutions to specific plant events where the present CANDU annunciation systems do not fully meet the needs of operations staff. Work is currently underway to improve the annunciation in three areas:

- At the Point Lepreau Generating Station, work is focussing on reducing annunciation message presentation rates for the alert phase of major plant upsets by improved prioritization.

- At the Pickering Generating Station, work is focussing on developing a critical safety parameter advisory system to improve the monitoring and management of critical safety functions during plant upsets.

- At the Bruce 'A' Generating Station, work is focussing on developing alternative control room displays that better assist operators in predicting and monitoring the operational margins of the steam generating system during transient conditions.

The following annunciation aspects will be addressed in these projects:

- confirmation of the annunciation-related operational tasks and their associated annunciation functions,

- further definition of the plant states and their associated parameter ranges; this is seen as key to achieving meaningful annunciation during plant transients,

- further definition of annunciation message categories and the criteria to be used to determine the overall message priority for a piece of plant information,

- further research into additional concepts for characterizing annunciation, and

- examining the issues associated with human trust in machines, where the achievement of overall functional objectives is dependent on the co-ordinated execution of the functional responsibilities of both humans and machines.

We expect that the functional role outlined in this paper and refined through continued studies will provide a sound basis for designing improved annunciation architectures for application in plant retrofits and new plant designs.

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REFERENCES

(1) O'HARA, J.M. and BROWN, W.S., "Nuclear Power Plant Alarm Systems: Problems and Issues", Proceedings of the Human Factors Society 35th Annual Meeting, pages 1233-1237, 1991.

(2) LIPSETT, J.J., OLMSTEAD, R.A. and STEVENS, J.E.S., "Balancing the Roles of Humans and Machines in Power Plant Control", presented at International Atomic Energy Agency Advisory Group Meeting on the Balance Between Automation and Human Actions, Vienna, Austria, 1989 April.

(3) CHARLEBOIS, P., "Computer - Friend or Foe?", presented at the CANDU Owners Group Computer Conference, Markham, Ontario, 1990 November 11-13.

(4) PAUKSENS, J., "Notes on Annunciation Management Breakout Session", Proceedings of CANDU Owners Group Computer Conference, 1990 November 11-13.

(5) LUPTON, L.R., LAPOINTE, P.A. and GUO, K.Q., "Survey of International Developments in Alarm Processing and Presentation Techniques", presented at the International Symposium on Nuclear Power Plant Instrumentation and Control, Tokyo, Japan, 1992 May 18-22.

(6) RASMUSSEN, J. "Information Processing and Human-machine Interaction - An Approach to Cognitive Engineering", New York: North-Holland, 1986.

(7) KELLY, R.J., BOULAY, D., FENTON, E.F., JOHNSON, A.R., MCCORMACK, G.R. and WHITE, M.W. "Emergency Operating Procedures Standards for Canadian Nuclear Utilities", Report prepared by the Joint Utility Task Group, 1987.