PROCESS MONITORING DURING NORMAL OPERATIONS AT CANADIAN NUCLEAR POWER PLANTS

Eric Davey
Crew Systems Solutions
Deep River, Ontario
Canada, K0J 1P0

This paper summarizes the findings from several observational studies to characterize the basis for a process monitoring strategy used by operators in 'normal' operations at CANDU nuclear power plants. These studies were undertaken in support of projects to develop improved control room displays and information systems to better support operators in both normal and abnormal operating situations. With the assistance of operators from several plants, an underlying basis for process monitoring was defined and a 'generic' strategy for monitoring process conditions in 'normal' operations has been established.

BACKGROUND

Role of Monitoring in Plant Operations

CANDU nuclear plants are designed and operated with the understanding that the senior control room operator is responsible, as the licensed operating authority, for all aspects of plant safety and production. In this role, the senior control room operator plans, organizes, directs plant operations, and configures and supervises automated systems to achieve operational objectives.

CANDU nuclear plants are highly automated. In stable production states, the control system maintains process conditions to established setpoints enabling continuous electricity production with minimal need for operator intervention. During maneuvers of the plant from one operating state to another, the control system automatically adjusts key process setpoints, and continuously adjusts process conditions to stabilize the operating point at the new operating state. In supervising this highly automated system, the control room operator must monitor selected plant parameters to:

- Confirm that the operating goals and conditions selected are being achieved as expected, and
- Detect indication changes that can provide early warning of developing disturbances.

Specification of Monitoring Practice

Until recently, the emphasis in formally establishing monitoring requirements and preferred behaviours within the CANDU community was confined to specification of operator responses to specific upset situations. In contrast, the specification of monitoring requirements and preferred behaviours in support of monitoring in 'normal' operations received less attention and was less formally documented. Monitoring emphasis and behaviours in support of 'normal' operations were learned through on-the-job practice, and informal adoption and adaptation of the behaviours of more experienced peers.

THE MONITORING ENVIRONMENT

The Control Room

Monitoring of the overall plant status is conducted from a central control room. The control room for a single-unit CANDU station consists of an open room approximately 20 metres square. Instrumentation panels occupy two walls of the room.

The control room also contains a central console that serves as the primary work area for the control room operator and his assistant. From this central

seated position, the operator coordinates all aspects of plant operation.

In monitoring overall plant operation, the operator uses information from several information systems and sources. The primary source of plant status is drawn from the information periodically scanned from six to nine computer-generated displays at console workstations and panel locations.

Characteristics of Normal Operation

'Normal' operation is characterized by extended periods of operation in predefined stable operating states and brief periods during which controlled maneuvers permit the transition between stable states. The preferred and most common operating state is Full Power Steady State where the plant produces it's fully rated electrical generation on a continuous basis.

During periods of continuous production, monitoring of plant status can be complicated by an ongoing series of plant changes. To support continuous production, changes in process conditions and the configuration of systems are introduced as result of on-power refueling, equipment maintenance and testing needs, and equipment failures and subsequent replacements. The supervision of these individual changes can reduce the time available for overall plant monitoring, and the operational impact of individual changes can reduce the detectibility of changes in the primary indications that are being monitored.

Monitoring Behaviours

Monitoring represents one of seven task group responsibilities assigned to the control room operator. Therefore, overall plant monitoring is performed on a semi-continual basis and individual-monitoring scans can frequently be interrupted by other task's needs for operator attention.

In addition, monitoring scope can be broad (i.e., overall plant), or narrow (i.e., focused on the consequences of individual operating actions), or require a combination of both.

In practice, three representative types of operator behaviours can characterize monitoring:

- *Periodic Monitoring* - Monitoring of stable production with no operating actions underway. Monitoring is initiated opportunistically at three to ten minute intervals at natural breaks in other tasks and is devoted to overall plant supervision.
- *Directed Monitoring* - Monitoring of stable production with some operating actions underway. Monitoring attention is split between supervision of operating actions and overall plant supervision needs.
- *Continuous Monitoring* - Near-continuous monitoring of critical operating actions (e.g., push of new fuel during fueling) and secondary supervision of overall plant conditions.

A MONITORING STRATEGY

Goal and Setpoint Based Emphasis

Monitoring behaviour is purposeful. At any time, the displays and indications monitored are related to the current operational goals being achieved. As operational goals change, the parameters of monitoring interest change accordingly.

Operational goals can be characterized by safety and production components. The primary safety goal is to protect plant staff, the public and the environment from all potential hazards of plant operation. The primary production goal is to produce electricity to meet electrical system demand at lowest total unit energy cost.

To achieve the production goal, a number of setpoints for plant process systems are established. Several automated systems are employed to provide continuous control of process conditions to the established setpoints for production purposes. As long as the production processes are operated to the established setpoints, both safety and production goals will be achieved. Both sets of goals may only become challenged when a process disturbance, equipment failure, or operating error occurs. Thus, operators remain confident that both sets of goals are being achieved when:

- The automated production systems operate at their established setpoints, and
- Special safety systems remain poised and available to fulfill their function if required to do so.

Information Sources Used

Operators monitor plant status using information from several sources, for example:

- Annunciation provides specific alerts to changes in any plant conditions that challenge safety and production goals,
- Periodic scanning of currently visible displays and panel indications provides an update to the current conditions for a small set of plant parameters,
- Selected viewing of displays that are not normally visible to learn of the current status of specific parameters, and
- Verbal reports from control room and field staff concerning process conditions and equipment states.

An operator's attentiveness to each source and monitoring behaviour is determined by his/her understanding of the operating and maintenance state of the plant. Under steady-state conditions, operators place a heavy dependence on:

- Annunciation to detect and alert them to important changes anywhere in the plant, and
- Periodic scanning of a selected set of continuously visible computer displays and panel indications to confirm the continued achievement of operational goals and to detect changes from normal conditions for key indications.

Type of Parameters Monitored

To confirm that the controlled process systems are performing as intended, operators focus periodic monitoring attention on three types of performance related indications:

- *Process Setpoints* - Current value and trend of process setpoints for major control functions,
- *Process Outputs* - Current value or error and trend of controlled process parameters, and
- *Internal Measures* - Current value and trend of parameters that provide early indications of the internal compensatory response of controlled functions to any disturbance.

For poised systems, operators have high confidence that these systems will be available to perform their intended function as a result of panel and system checks conducted each shift that confirm their availability, and annunciation of system failures. Thus, regular monitoring of the status of these systems is not needed.

Operational Context

The specific parameters to be monitored are dependent on the plant operating state. For example, during 'normal' operations at Full Power Steady State conditions, the key setpoint, process output and internal measures associated with the five primary controlled functions of the power generation cycle are monitored. These functions are:

- Reactor Power Control,
- Heat Transport Pressure and Inventory Control,
- Secondary Steam Generator Level Control,
- Secondary Steam Generator Pressure Control, and
- Turbine Control.

During outages, the monitoring emphasis shifts to confirmation of unit safety-state, specifically parameters affecting the Guaranteed Shutdown state conditions, reactor power levels, fuel cooling, and heat sink status.

Information Form

For monitoring purposes, operators prefer display formats that show trends with time, highlight early departure from normal values, indicate margins to initiation of protective actions, and permit visual comparison of related indications.

IMPROVING MONITORING SUPPORT

At all CANDU plants, the initial set of displays to support monitoring was drawn from the available suite of system-based process displays provided by the design team. With operational experience and as the understanding of monitoring needs have evolved, many of these displays are no longer effective to support current monitoring objectives.

Compensatory Practices by Operators

To address some of their monitoring display needs, operators have undertaken the following display customizations within the configuration limits of existing display systems:

- *Parameter Substitutions* - Replacement of current display parameters that are not used, with parameters relevant to current monitoring objectives,
- *Range Magnification* - Use of narrowed display ranges and multiple stacked trend formats to facilitate disturbance detection, and
- *Definition of Task-based Displays* - Definition of displays with parameter groupings more supportive of specific monitoring task needs.

Display Improvement Initiatives

With improved understanding of the operators working environment and monitoring needs, utilities and design organizations are undertaking the following initiatives leading to monitoring display improvements:

- *Operators as Members of Design Teams* - Addition of operators to display design teams to facilitate more complete definition of needs and more timely refinement of design concepts.
- *Functional Display Organization* - Application of a common functional ordering of parameters in monitoring displays for plant functions,
- *Formalizing Operating Envelope* - Projects to better characterize reference operating margins for 'normal' operations (Lane, 2000), and
- *Definition of New Display Formats* - Creation of new display formats to better address monitoring and situational task needs (Davey, Tonello and Rivera, 1999).

CONCLUSIONS

With the participation of operators from several plants, a 'generic' strategy for monitoring process conditions in 'normal' operations has been defined. Application of the components of this strategy can:

- Account for the use of specific monitoring behaviours, preferences for parameter content and form, and display layouts in current plants,
- Assist in identifying opportunities for display improvement within the constraints of legacy display systems, and
- Provide a sound basis for formalizing and training staff in improved monitoring practices.

ACKNOWLEDGMENTS

The author would like to acknowledge the assistance of Operating and Training colleagues at the Point Lepreau, Pickering, and Darlington plants who have contributed to the author's understanding of plant monitoring needs and practices. In particular, the observations and insights of Bill Artiss, Pete Hartley, Keith Herzog, Lee Lane, Tim Long, Bill MacEwen, Tom Myles, Wade Parker, Jim Richards, John Richardson, Brian Smith, Mark Tonello, and Glen Wood were most influential.

REFERENCES

Davey, E., Tonello, M., and Rivera, D. Control Room Monitoring of Process Conditions and Identification of Improvements to Darlington Monitoring Displays. Paper presented at the Canadian Nuclear Society Conference, Montreal Quebec, 1999 May 30 to June 02.

Lane, L. Plant Status Control with an Operational Focus. Paper to be presented at the Canadian Nuclear Society Conference, Toronto, Ontario, 2000 June 11-14.