RETROFITTING ALARM PRIORITIZATION AT BRUCE A: STRATEGY DEVELOPMENT AND IMPLEMENTATION EXPERIENCE

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ABSTRACT

A prioritization strategy for computer-displayed control room alarms has been developed for Bruce A to better assist operations staff in visually identifying key alarms and judging the relative importance of alarms. The strategy consists of assigning each alarm indicative of a problem to be addressed to one of five priority categories. Each alarm is assigned to an alarm category based on an off-line analysis of the consequence characteristics applicable to the alarm for three plant operating contexts. The colour of the alarm message is used to convey the priority category of each alarm in computer-based alarm displays. In addition, alarms indicative of non-problematic changes in the state of plant equipment and processes are given a separate colour assignment to visually differentiate them from alarms indicative of problems.

This paper outlines the user-based approach employed in the prioritization strategy development, describes the key features of the prioritization strategy adopted, and discusses the initial experience in systematically determining the priority assignments for all 8000 computer-based alarms associated with each generating unit.

BACKGROUND

CANDU plants employ computer-based alarm systems to alert control room staff to abnormal operating conditions and changes in plant configuration as a result of the automatic responses of plant automation. This annunciation, along with the routine monitoring of control room displays and field communication, enables operations staff to keep up-to-date with the current plant conditions and predict future plant states.

Current CANDU alarm systems are implemented as part of the plant digital control computer software and contain a database of several thousand alarms that provide coverage for all plant safety and power production functions.

At Bruce A, alarms are presented on the control room annunciation displays with no indication of importance or priority. Consequently, operators are required to judge the relative importance of each alarm in real-time and adjust their response to plant conditions accordingly. This approach is acceptable for plant states where the alarm generation rate is low (e.g., stable full power steady state conditions). However, for other phases of plant operation, such as manoeuvres, upsets or outages, the operator's task to identify important alarms among many active alarms and to prioritize response actions based on determining the relative importance of each new alarm becomes more complicated.

As part of a major station retrofit program, the capabilities of the control room computer-systems were being improved and modernized for Units 3 and 4. This development which has been recently discontinued, would have allowed designers to retrofit substantial improvements to the control room alarm systems. One development initiative would have been the visual indication of priority for all computer-displayed alarms.

OPERATIONAL BENEFITS OF PRIORITIZATION

The operational objectives of indicating the importance of each displayed alarm are:

- to alert operators to (i.e., visually draw attention to) the alarms of most immediate importance for preserving safety and meeting production objectives, and
- to assist operators in ordering their response when multiple alarms are annunciated.

Alarm prioritization is not expected to have equivalent operational benefit across all plant operating phases. The anticipated benefits of visually indicating alarm priority are summarized in Table 1 as a function of operational emphasis, rate of alarm state changes and number of alarms active for each operating phase.

Prioritization is expected to be of greatest benefit during instances where many alarms are active and alarms are frequently being created or clearing, and operators are busy with many tasks (e.g., startups, shutting down, outages and after the first few minutes of an upset).

Prioritization is expected to be of less value during full power operation as few alarms are active and operators normally have time to consider and prioritize alarms themselves, as with current practice. Additionally, prioritization has little value in the first few minutes of upset response as operators rely on increased panel monitoring and window annunciation to keep abreast of important plant changes during their initial response activities.

Table 1
Expected Benefits of Alarm Prioritization by Operating Phase

Operating Phase	Operational Emphasis	Rate of Alarm State Changes	Number of Alarms Active	Perceived Prioritization Benefit
Stationary Conditions				
Full power operation	Safety and Production	< 3/min	< 10	Little
Shutdown	Safety	< 5/min	> 40	Some
Changing Conditions				
Startup	Safety and Production	> 5/min	< 40	Substantial
Shutting Down	Safety	> 5/min	<50	Substantial
Outages	Safety	< 5/min	> 150	Substantial
Upsets (0-3 min)	Safety	> 50/min	> 200	None
Upsets (>3 min)	Safety	> 25/min	> 150	Substantial

DEVELOPMENT APPROACH

The development team employed a user-centered, and goal-directed approach in establishing a practical alarm prioritization strategy for Bruce A. Examples of the key information sources used and activities applied include:

- *Station Visits* - Interviews were held with Bruce A operations, training, licensing, and engineering staff who were involved with annunciation use, maintenance and improvement to understand the needs for both users and those who would have to support any prioritization implementation.
- *CANDU Annunciation Experience* - The development team drew on CANDU alarm prioritization experience at other plants (1) and a recently completed CANDU Owner's Group (COG) annunciation improvement program (2).
- *Control Room Observations* - Observations of annunciation characteristics and usage by Bruce A operations staff assisted the development team in confirming current station practice for judging alarm importance.
- *Task Analysis* - Detailed analyses of operator tasks in using annunciation at Bruce A (3) and CANDU plants in general (4) were reviewed to further clarify operational practice and prioritization requirements.
- *Station Operating Principles and Practice* - Station operating and training documentation was reviewed to confirm aspects of preferred annunciation operational practice.

- *Engineering Project Constraints* - Discussions were held with engineering staff to clarify and confirm project and on-going support constraints that limited the scope of options available for prioritization implementation.
- *Peer Review* - The proposed alarm prioritization strategy was subject to a Peer review by representatives of Bruce A operations, training, operations support, licensing, safety analysis and engineering staff to confirm the approach and identify suggestions for improvement.
- *Pilot Testing* - Alarms representative of all types of Bruce A alarms were prioritized using the proposed prioritization strategy by four operations and training staff to confirm the operational relevance and repeatability of priority determinations and estimate the effort for a full plant prioritization analysis.

The initial strategy development was lead by operations and annunciation analysts from AECL, Chalk River Laboratories who drew on the collective experience of Bruce A operations, training and engineering staff. A key factor to the success of the project was the strong participation of operations and training staff in initial concept development and pilot testing of the proposed alarm prioritization approach.

CONSTRAINTS

The proposed prioritization strategy was required to be compliant with several operational and design aspects. Examples of key constraints for prioritization strategy selection were:

- *Support for Operator Decision-Making* - In their role as overall supervisors, operators make the final determination of an alarm's importance based on the expected consequence to the plant, current plant state and expected trend in plant conditions. Any predefined alarm importance indication must be based on similar factors and be viewed as preliminary information to be confirmed by the operator prior to initiating response actions.
- *Coverage* - The selected prioritization approach had to provide alarm priorities that are relevant for all plant situations and scenarios.
- *Alarm Systems Consistency* - Operators must integrate and prioritize their response to alarms from several systems. The prioritization approach selected had to be compatible with the prioritization approaches and coding employed by other alarm displaying systems.
- *Control Room Consistency* - The Bruce A control room operations would involve a mix of upgraded equipment (e.g., Units 3 and 4) and original equipment (Units 0, 1 and 2). Thus, any alarm prioritization approach adopted for Units 3 and 4 had to be consistent with the manual alarm importance determination method still in use on non-upgraded units. Consistency of alarm importance determination approaches is important since staff from different units assist each other during power manoeuvres, upsets and unit monitoring during breaks.
- *Compliance with Alarm System Design* - To be of value, the selected prioritization approach must provide operational benefits within the envelope of the alarm processing and display capabilities provided by the upgraded control room equipment. Key processing and display constraints included: no additional alarm conditioning, retention of a chronological

presentation of alarms and a single priority assignment for each alarm that must cover all plant operating contexts.

- *Validity* - To limit the extent of validation effort and establish operator confidence rapidly, the selected prioritization approach had to have high 'face' validity. Factors contributing to high 'face' validity include: conceptually simple, few and well-defined failure modes, and operationally proven in other process applications.
- *Project Schedule* - To accommodate the existing project schedule, the initial prioritization analysis had to be accomplishable in eight weeks.

STRATEGY DESCRIPTION

Decision-Making Allocations

CANDU operations, training and engineering staff have consistently identified three factors as essential components in determining alarm importance and thus priority (2). These three factors are:

- *Context* - the current plant state and operating trends within which individual alarm importance should be judged.
- *Consequence* - the impact on plant safety or production that the annunciated condition will have.
- *Response* - the nature of response required and the timeframe for response to the annunciated condition.

Consequently, the development team employed these three factors as the basis for structuring a Bruce A alarm prioritization strategy. An alarm importance determination approach where operators would retain overall judgment of relative alarm importance but would be provided with a predefined indication of alarm consequence was recommended as best meeting the operational objectives and overall constraints

Consequence Categories

Operators must rationalize safety and production concerns simultaneously as part of their normal response to alarms. Based on the plant conditions, and the nature of alarms, operators decide on a response that provides the best fit for balancing current safety and production concerns. Thus, an alarm categorization approach was selected that could support such practical decision-making based on an ordered list of alarm consequence categories that address safety and production priorities in an integrated way.

A set of five consequence categories was proposed as shown below in order of decreasing consequence:

- *Major Safety State Challenge* - Special safety system actuation or challenges to critical safety parameters.

- *Operating Policies and Procedures Non-compliance* - Operating configurations challenging or exceeding the licensed limits.
- *Major Process Upset* - Conditions that result in a significant change in generation or heat sink capability, examples include setbacks, stepbacks, reactor or turbine trips, and loss of key common services such as instrument air, power or cooling water.
- *Challenge to Desired Plant State* - Minor conditions or upsets that present a challenge to preservation of safety or production objectives, examples include low boiler, condenser, deaerator, zone levels; loss of redundancy or fault/tolerance, and less economic operating configurations.
- *Compensatible Upsets and Damage* - Process upsets and equipment damage for which an automated means or readily available operator selected means of compensation is available.

Contexts for Consequence Category Assignment

Experience in the CANDU Owner's Group annunciation improvement program had shown that it is more effective and representative to determine alarm consequence for specific plant operating contexts rather than attempt an alarm consequence selection by assuming all plant situations and scenarios must be accommodated within one determination.

Three operating states were selected for use in alarm analysis to provide representative coverage for all plant operating contexts. The recommended operating states applied as contexts for alarm analysis were:

- *Full Power Operating State* (i.e., base load full power generation),
- *Zero Power Hot State* (i.e., low power, boilers as heatsink, primary and secondary systems warmed up), and
- *Overpoisoned Guaranteed Shutdown State* (i.e., moderator overpoisoned in guaranteed shutdown condition and maintenance cooling as heatsink).

The results from alarm consequence determinations in each of these three operating states would be rationalized to select the overall alarm consequence category assignment to be applied for display use. A conservative selection strategy based on selecting the highest consequence category assigned to the three operatating states was recommended for use.

Fault/Status Differentiation

Operational experience and past designs have proven that two types of alarms (i.e., faults and status) are both important to supporting operators in their supervision and control of plant processes and systems. Faults are alarms that indicate process conditions have exceeded their normal expected range or equipment state and are no longer acceptable for the current plant operating conditions. Status alarms are alarms that indicate a change in process conditions or equipment state that the operating crew should be alerted to but are not viewed as problems.

Experience in other nuclear power plants (5) and the CANDU Owner's Group annunciation improvement project (2) have demonstrated that visually differentiating these types of alarms assists operators in alarm response. For example, operators focus more attention on faults than status alarms during disturbance and upset conditions.

Alarm Displays

The consequence and fault/status information for alarms is visually coded in alarm displays by the colour of the alarm message text. Each consequence category is assigned a separate colour. Thus, the colour of the text of a fault alarm indicates it's assigned consequence category. Status alarms are coded by means of a separate and sixth colour assignment to differentiate them from fault alarms.

IMPLEMENTATION EXPERIENCE

Procedure Development

An alarm analysis procedure and supporting guidance (i.e., forms, categorization rules) were developed to assist analysts in alarm classification and consequence determination. The procedure involved five steps:

- *Sorting alarms for Uniqueness* - Presorting alarms can reduce the overall analysis effort by ensuring that only one alarm from each group of common alarms (e.g., channelized indications) is analysed. Presorting alarms can reduce the number of alarms to be individually analysed from a third to a fifth of the alarm total.
- *Alarm Identification* - Recording the alarm identity information (e.g., identification code, message text and annunciated condition to be analysed).
- *Fault/Status Assignment* - Assignment of each alarm as either a 'fault' or 'status' indication based on its purpose.
- *Consequence category assignment* - Assignment of each fault alarm to one of five consequence categories based on the expected consequence in each of three representative plant operating states.
- *Recording of Assignment Rationale* - Documentation of the rationale for each fault/status and consequence category assignment chosen. Experience has shown that a description of the rationale for assignment decisions is very useful during initial verification review and later use or modification of specific assignments.

Review and Pilot Testing

The proposed alarm prioritization strategy was evaluated in two ways. First, a review of the strategy was conducted with Bruce A station staff representative of several areas of plant operations. Second a pilot test of the proposed alarm prioritization procedure was conducted with four operations staff serving as alarm analysts.

Key findings from these reviews included:

- *Approach Suitability* - the proposed alarm prioritization approach was judged to be practical and produced operationally relevant results,
- *Fault/status Differentiation* - visually differentiating fault versus status alarms is expected to assist operators in alarm recognition and interpretation,
- *Documenting Decision Rationale* - recording the reasons for consequence and fault/status assignments was important for supporting later verification review and future assignment modification,
- *Teaming for Analysis* - a number of factors (e.g., broader experience available and the benefits of discussion) contributed to more effective and efficient consequence and fault/status assignments when analysts worked together in teams rather than singly.
- *Analysis Effort* - a full plant alarm analysis was estimated to be accomplishable within two person months.

Plant Alarm Analysis

Following the successful pilot test, effort shifted to the full-scale engineering implementation of the approach. This involved categorization of several thousand alarms into fault and status categories and the assignment of a consequence category to each alarm. This analysis was undertaken by a team of two operators and completed over a six week period. To simplify the management of alarm information and searches for specific alarm properties, an alarm analysis support tool was developed based on a relational-database and customized analyst interface displays. The use of such a tool improved the effectiveness of the analytical team by minimizing the time required in alarm record sorting and management, and enabled analyst efforts to be focused exclusively on fault/status and consequence category assignments.

CONCLUSIONS

An approach to categorizing and prioritizing computer-displayed alarms for Bruce A NGS Units 3 and 4 has been developed and station implementation is partially complete. The prioritization approach selected is based on the same factors and assists the same alarm importance determination reasoning as currently practiced by operations staff. In addition, the approach is consistent with the prioritization approach and visual coding applied to the annunciator window alarms. The initial application experience has confirmed that the procedure established for priority assignment determination is practical, can be applied in a cost-effective manner, and leads to reproducible priority determinations from independent analysts.

ACKNOWLEDGMENT

Many people have assisted the authors in developing and implementing a practical alarm prioritization strategy for retrofit to Bruce A alarm displays. First, the authors would like to acknowledge the experiences and insights shared by Bruce A operations colleagues who depend on the station annunciation systems from shift-to-shift. Second, we would like to acknowledge the contributions of Bruce A training, licensing and design staff within the station community who have supported us in strategy development and application.

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