SUPPORTING HUMAN PERFORMANCE IN OPERATIONS -

PRINCIPLES FOR NEW NUCLEAR BUILD

by

Lee Lane
Darlington Nuclear Division, Ontario Power Generation
Bowmanville, Ontario, L1C 3W2

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

ABSTRACT

Operational experience worldwide continues to demonstrate that human performance is a key factor in the ongoing safety, production, and protection of investment in operation of nuclear plants for electricity generation. Human performance in support of plant operational objectives can be influenced by a range of factors, for example: organizational culture and expectations; role assignments, training, and individual and team behaviours; and the support offered by the workplace environment, tools, and task design.

This paper outlines a perspective on some of the principles that should be considered for application in the design of new nuclear build to facilitate support for human performance in plant operations. The principles identified focus on but are not limited to the tasks of shift staff, and are derived from the observations and experience of the authors who are experienced with control room operations in current plants.

INTRODUCTION

Nuclear power plants are large, complex electrical generation facilities that are operated under a combination of human and automation control for the purpose of electricity generation. Plants are designed and operated with the understanding that human operators are ultimately responsible as licensed authorities for plant safety and productive operation.

In conducting plant operations, human operators plan, organize, direct plant operations, configure automated systems to achieve operational objectives, and maintain the operational state of plant equipment. In support, plant automation continuously controls processes to operator-selected setpoints, monitors performance, detects and alerts operators to abnormalities, and automatically intervenes to place the plant in a safe shutdown state when safety goals are challenged.

The degree of excellence achieved with human performance in the workplace can be influenced by a broad range of factors. One classification of these factors and specific examples include:

- Regulations - Industry rules, directives, and standards,
- Organization - Corporate culture, structure, management practices, and performance reward policies,
- Workgroup - Staffing, role assignments, authority, communication and team practices, and training,
- Operational - Goal priorities, and task requirements, familiarity, design, and guidance,
- Workplace - Layout, organization and accessibility of work area, information sources and controls, tools, environmental lighting and noise, flexibility for future enhancements in technology and human performance, and
- Individual - Knowledge, skills, motivation, stature, workplace behaviours, and fitness for duty.

Plant designers and operating utilities have always recognized the essential contribution of humans in performing tasks to support achievement of plant safety and production objectives. For example, ergonomic principles have always been applied to varying degrees in guiding plant workspace design, and utilities have created and run training programs with extensive initial, on-the-job, and refresher program aspects to ensure staff have the system and operating knowledge and experience to perform their assigned duties.

In the eighties and nineties, examination of industry performance and specifically factors contributing to individual plant safety challenges and chronic unrealized production potential led industry leaders to recognize that human performance limitations were preventing the improvement of industry performance. Consequently, a number of new initiatives focusing on human performance improvement (e.g., training in individual and team safe operating behaviours, and human factors programs as part of station changes) have been retrofit to supplement former human performance practices.

The prospects for new nuclear build offers an opportunity to build in support for enhanced human performance from a project beginning. In the spirit of getting it right as much as possible in the beginning, the lessons learned from operating experience and human performance initiatives in current plants should be consolidated into design guidance for consideration in new build.

With this opportunity in mind, this paper identifies some design principles derived from operator experience in current stations. The authors believe, these principles if adopted would lead to more supportive systems and workplaces leading to enhanced human performance in future station operating environments. The principles cited represent one perspective on current plant experience, and should be combined with the lessons learned from other experience and human performance improvement initiatives.

BACKGROUND

Human performance refers to the degree of desired accomplishment achieved by human actions in performing assigned tasks in support of operational goals. In power plants, operational goals may be achieved through a combination of automation and human performances, or via automation or human performances separately.
Human performance can be measured in a number of ways, for example, the accuracy, timeliness, reliability, completeness or degree of error with which actions are undertaken.

As discussed earlier, the degree of success in human performance achievement can be affected by a number of factors associated with the work environment, task properties, work team organization, tool properties, and characteristics of individuals performing the work. Consequently, efforts to improve human performance in the workplace in nuclear plants have been addressed by a number of initiatives with a variety of areas of emphasis, for example:

- Training - Utilities have used formal instruction and practice in operating actions as the means for workers to learn and practice skills prior to use. Training can be used to reinforce preferred workplace behaviours and standardize operating actions across shift crews. This initiative supports human performance in that it ensures the readiness of workers for performance of assigned task duties.

- Procedure Use - The availability of written instructions for a task reduce worker dependence on memory recall in deciding on task actions. Adherence to use of procedures supports human performance in the workplace by fostering standardization of operating actions across crews and work situations, and reducing the potential for human error from faulty recall and/or workplace distractions.

- Validation Prior to Use - Validation is the evaluation of a work practice, procedure, system, or team arrangement through an operational test prior to introduction into operating service. The purpose of validation is to confirm that the operational goals for a work practice, procedure, system, or team arrangement can be achieved in representative operating environments. Thus, validation supports human performance in operations by confirming the sufficiency of support provided to workers by design of the workplace, environment, and tools prior to introduction into service.

- Functional Perspective in Design - The purpose of plant systems are to perform operating functions in support of plant safety and production goals. Consequently, a functional emphasis in system design and description will emphasize defining and documenting how the system is to be configured, operated and maintained in use. This perspective supports human performance since it encourages designers to think beyond provision of capabilities in response to design requirements, to how system equipment is to be operated and maintained. It is also an opportunity to consider user interfaces, consistency of approach as related to the 'big picture' operation, and adaptation to future enhancements in operability and maintainability.

- Adoption of Human Factors Programs - In the eighties and nineties, standards and guidance evolved for the formal incorporation of human factors design support activities in system design [1,2,3]. The purpose of this initiative was to ensure that a systematic approach is taken in specification of the human role and provision of support for human actions during design of system elements and workplaces. This initiative supports human performance in that it requires designers to analyse user support needs, design to support them, and confirm the effectiveness of design solutions as part of the system design scope.

- Learning from Experience - Industry operational experience programs encourage utilities staff to report and analyze events, and identify and implement improvements using both local and industry experience. This initiative supports human performance since the sharing of experience on events and continuous improvement initiatives helps utilities avoid repeat events and learn from the best practices of their peers.

- Human Error Reduction - In the nineties, the Institute of Nuclear Power Operations (INPO) developed a program to reduce human error in plant operations [4]. The program focused on improving behaviours and work practices at the individual, leader/supervisor, and organization level within an operating organization. Behaviours are the way an individual, team or organization acts in performing task duties in response to a particular situation; consequently, behaviours directly control the potential for task accomplishment in the workplace. This initiative has improved human performance in the workplace by equiping workers and supervisors with behaviours that support safe operating practices and provide additional resistance to error occurrence.

In practice, achieving enhanced human performance involves getting many things right in a number of areas, and ensuring that work and workplace decisions in one area do not constrain or restrict the application of human performance enhancement practices in another.

With the current generation of CANDU plants, design and initial operational definition preceded creation and application of several follow-on human performance initiatives. Consequently, work situations exist in current plants where original design and organizational aspects constrain or limit achievement of excellence in human performance in the operating workplace.

APPROACH

The authors' objective was to identify task-based principles applicable for consideration in new nuclear build that would lead to plant features providing enhanced support for achievement of excellence in human performance in support of operating activities.

The following approach was used in formulating the principles discussed in this paper:

- Scope and Organization - Selection of the scope of task experience to review and means to organize principles,

- Consideration of Experience - Identification of work situations and the key factors associated with current plant design and operations that support or limit human performance in the workplace, and

- Formulate Principles - Develop suggestions for principles that would lead to new build designs being more supportive of human performance in operations.

Tasks associated with operator duties in the control room were selected as the task scope for review since these tasks are central to all shift operations and were familiar to both authors. The operator tasks considered were organized into seven functional groups based on a categorization applied in a previous study [5]. The seven task groups are:

- Planning - Tasks associated with preparing and prioritizing work,

- Plant Awareness - Tasks associated with developing and maintaining an understanding of current process status, equipment configuration, and shift work status,

- Supervising - Tasks associated with providing work direction, oversight and assessment,

- Control - Tasks associated with performing operating actions to change process and equipment state,

- Response - Tasks associated with understanding and responding to disturbances,

- Maintenance - Tasks associated with planning, directing, and overseeing equipment servicing, and

- Recording - Tasks associated with preparing shift operating records.

PRINCIPLES FOR SUPPORTING HUMAN PERFORMANCE

This section lists the principles identified from an examination of control room operator duties. The principles are organized by the seven task functional groups discussed previously. The listing of principles is not ranked nor should the principles described be considered as a complete list.

<u>Planning</u> - Preparing and prioritizing work.

- Information Alignment (Configuration Management) - Ensure the plant as represented in paper and electronic representations, are aligned with the physical 'as built' plant.

  Plant operations are dependent on a common view of the plant across paper, electronic and physical representations. Where information doesn't match, extra work and investigation is required to resolve differences before work can proceed. Misalignment of information can also create error latencies that can introduce increased potential for operating and maintenance errors via misdirection. Emphasis should be put on achieving alignment of these three plant perspectives in design and construction to avoid passing information inconsistencies into use in commissioning and subsequent operations. With the onset of new computer technologies, managing configuration has continued to become more achievable. Cutting corners on Configuration Management during the build phase will cost more in the future of plant operation. With over 500,000 components to manage in plant operation, having accurate equipment information and strong Configuration Management is critical to operability, maintainability, and safety.

- Nomenclature - Ensure a single equipment nomenclature is applied and enforced across all design disciplines and equipment vendors.

  Each design discipline and equipment vendor brings local preferences for equipment naming conventions. To minimize confusion in integrated operations, a single equipment nomenclature should be defined and applied during design to eliminate the work delays and investigative work necessary to clarify misunderstandings. Typical misunderstandings are encountered during information use in commissioning and operations when the same term has different meanings across systems, or different terms are used in the identification of the same device. Application of a common single nomenclature minimizes misunderstandings in the workplace. The use of a common nomenclature should also be agreed with external groups who interface with station operations and communicate about the configuration or maintenance of shared or interconnected equipment (e.g., electrical grid operations staff).

- Work Management - Specify the work management process and design the plant systems, workspaces, and information systems to support it.

  The work and business processes required to support plant operation should be specified as part of the plant functional characterization prior to detailed design. In this way, the design and implementation of plant systems, workspaces, communication, and information systems can be designed to support this fundamental work planning process. With current generation plants, work management processes were defined by utilities following plant design commitment. This has resulted in inefficiencies in work management execution as a result of limitations in layout, communication, and information accessibility which contribute to ineffectiveness in achievable human performance. Day-to-day management of station work is a key business process that successful plant operation is dependent upon and shift roles, organizational design, the plant layout, information systems, and equipment should be optimized to support effective work management.

- Master Equipment List - Establish a master equipment list and enforce entry conformity at the beginning of design and throughout construction and station operating life to ensure all equipment is always adequately identified and described in a consistent and complete manner.

  The Master Equipment List is the stations engineering, operations and maintenance backbone. The operation of station design change, work management, and maintenance processes are dependent on the availability of adequate equipment identification and a complete description of plant equipment. Where information is incomplete or inaccurate or spread among several record sources, planning becomes inefficient, equipment may not be serviced appropriately, and extra investigative effort is required resolve information discrepancies. For example, in 1998 it was realized that the Darlington facility had over 20 official equipment databases, and there were inconsistencies between all of them. Experience has shown that building a master equipment list following plant design or during commissioning is time consuming and prone to incompleteness. Establishing the information standards for identifying and describing equipment in the beginning of design allows all equipment to be catalogued in a consistent and comprehensive way, thus better supporting human performance with it in downstream operational use.

<u>Plant Awareness</u> - Developing and maintaining an understanding of plant status.

- Status Visibility - Ensure plant status is fully visible to all control centre staff, and in fact, to all station staff.

  An understanding of overall plant status provides the context for judging the acceptability of system performance, aligning individual work consistent with plant state, and selecting appropriate operating actions in support of work team operational goals. In current generation plants, an understanding of plant status must be assembled from viewing information in several locations. In some control room work locations, all information is not visible, imposing dependence on verbal communication among team members for sharing key information. In times of high work demands such as plant manoeuvres, outages or upsets the effort to access information in multiple locations and share information via verbal communication can breakdown leading to less effective human performance. To coordinate team operating actions and reduce dependence on verbal communication for sharing information, control room staff should be supported by a common and accessible view of information from a single information presentation that is legible from all staff work locations within the control centre workspace and beyond.

- Status Content - Include the presentation of work priorities and status with the presentation of plant process status and equipment configuration.

An understanding of plant status requires knowledge of plant process and equipment states and configuration, as well as the current work priorities and status. Just as the status of the plant operating state provides a context for determining appropriate operating actions, so to do current work priorities and status provide a context for planning shift work. In current plants, information on work priorities and status is distributed among several control room information systems, requiring secondary effort to access and understand, and communicate to team members. Developing and maintaining overall plant status awareness could be substantially simplified if both types of information were readily viewable from all control centre workplace locations.

- Monitoring - Structure the workplace environment and crew responsibilities so that monitoring tasks can be performed with minimum distraction or disruption.

  Analysis of operating events in a number of work domains has highlighted the risks to safety, production and facility investment that loss of supervisory oversight can cause. To minimize the potential for losses in monitoring oversight in the future, workspaces where monitoring is a prime function should be structured to specifically support those individuals in monitoring roles. This requires division and allocation of work so that monitoring is not compromised by other duties, and configuration of monitoring workspaces to minimize the disruption from adjacent work and environmental distractions.

- Change Detection - Structure displays to make changes in information highly salient and recognizable.

  In supervising plant operations, control room staff continually check plant configuration and processes remain aligned with reference values. In order to detect departures from reference conditions in a timely and consistent manner, operators and supervisors need to be supported by information displays that assist in change recognition and assessment, rather than just portray parameter status. Giving display prominence to changes will support users in change detection and reduce the potential for significant parameter changes going un-noticed. Capacity should also be provided to allow for adoption of future change detection enhancements as technologies improve.

<u>Supervising</u> - Providing work direction, oversight, and assessment.

- Workspace Capacity - Provide spare workspace to support accommodation of above normal work management demands.

  Station operating experience has demonstrated an ongoing need for additional control centre workspace to be allocated on a temporary basis in support of management of peak work demands. During commissioning and outages, larger work teams are assembled and directed from the control room. These larger teams need additional workspace to hold discussions, review work, brief field teams on proposed work, and store job records on a temporary basis. If additional workspace is not available, the workspace for monitoring unit operations can become overly congested with the increased risk of impacting the human performance of all work adversely. Again, it is important to provide some flexibility as roles and technologies change in the future.

- Information Organization and Use - Structure information accessibility and integration to support task use.

  Information accessibility and display organization should be customized to task needs to simplify use. As control centre operational needs evolve, there will be continued expansion in control centre information resources, systems and capabilities. To exploit these added resources effectively, the secondary tasks in accessing, managing display space, and mentally translating and integrating information from multiple sources must be minimized. This requires a shift to a deeper information design practice to support human performance in use rather than just simple information accessibility.

<u>Control</u> - Performing operating actions to change process and equipment state.

- Standardization - Limit the variability in controls representation, behaviour, and operating actions for similar equipment.

  Variations in interfaces and operating actions for similar control devices, increases operating complexity, operator memory demands, and the risk that the wrong operating behaviour may be applied. Standardization of interfaces and operating actions for similar equipment simplifies operations and initial equipment training and helps promote excellence in human performance in use.

- Error Detection - Support self-detection of human error.

  Human error remains a major contributing factor to operational events, and some human, environmental and workplace characteristics that can't be fully eliminated can promote human error initiation. When errors do occur, humans readily detect and self-correct a high percentage of errors before the consequences of the error are realized. To exploit this error detecting and correcting behaviour, system interfaces and work practices should be designed to assist users in recognizing error occurrence in the workplace. Ideally, the solutions chosen should be independent of the need to standardize equipment interface features and coding conventions via custom or special purpose design or vendor equipment customization.

- Error Recovery - Support reversibility of operating actions.

  To recover from errors in operating actions when self or peer detected, operators need the ability to reverse operating actions prior to consequences from the original action taking effect. Equipment controls and interfaces that support undoing operating actions enable operators to self-correct errors in operating actions.

Response - Understanding and responding to disturbances.

- Eliminate Information Overload - Limit information presentation rates to user reception capabilities.

  When disturbances and upsets occur, plant processes and equipment can undergo rapid and many changes of state. In such instances, information systems that report every low-level change such as alarm systems, flood displays with large amounts of information operators are incapable of keeping up with. This represents a breakdown in information system support for user human performance. In such instances, operators have been trained to temporarily disregard use of such systems and rely on procedures and directed monitoring to respond to the disturbance or upset. In all operating states, the rate of information presentation should not exceed the fundamental capacity of an individual to recognize and understand each information element.

Maintenance - Planning, directing and overseeing equipment maintenance.

- Maintenance Status - Display an overview of unit maintenance status.

  Developing, maintaining and communicating plant maintenance status is an ongoing shift challenge and peaks during outages. Current information tools for tracking maintenance status are text-based, requiring time to understand information and develop an overview understanding of all work. An externalized overview representation of plant maintenance status that is accessible to all staff in the control room workspace and field work areas, could substantially simplify shift staff communication concerning specific maintenance work, assist in pre-job briefings, make field workers more aware of related systems work in their work area, and reduce miscommunication associated with the current heavy dependence on verbal communication.

- Oversight of Work - Design equipment workspaces and features to support supervisory oversight.

  Maintaining supervisory oversight of work is a key principle in promoting enhanced human performance in plant workplaces. Equipment workplaces should be designed with supervisory oversight needs in mind (e.g., space, lighting, remote reporting of service status, and assignment of dedicated work areas where warranted) to support application of human performance program principles.

Recording - Preparing shift operating records.

- Information Sharing - Eliminate the need for manual transcription of information between plant information systems.

  A limitation with many current control centre systems is that information in one system may not be readily electronically shared with information in adjacent systems. This can be due to communication barriers, and application of differing information conventions and formats. When information can't be electronically shared between systems, operators must manually transcribe information from one system to another. Such tasks are error prone, time intensive, and take operating staff away from their primary operating duties. Designing information systems to support ready communication of information between functions and databases can enhance human performance by eliminating time-intensive and error-prone manual transcription tasks and simplify overall work for operations staff in preparing shift records.

CONCLUSION

This paper has described some principles for consideration in new nuclear build that would result in the design of workspaces and systems in new plants being further supportive of the performance of operator control room tasks. These principles should be considered as complementary to other plant design and operating organization human performance initiatives that will be carried over from the experience with current generation plants, and open to further refinement as we continue to learn.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the contributions and support of operating and training colleagues within Ontario Power Generation. The operating observations and insights shared by these colleagues have helped the authors identify and organize the human performance support principles outlined in this paper.

REFERENCES

1. Design for Control Rooms of Nuclear Power Plants. International Electrotechnical Commission standard IEC 964, Geneva, Switzerland, 1989 March.

2. Human Factors Engineering Program Review Model. United States Nuclear Regulatory Commission report NUREG-0711 Revision 2, Washington, DC, 2004 January.

3. Human Factors Engineering Program Plans. Canadian Nuclear Safety Commission regulatory guide C-276, 2001 March.

4. Excellence in Human Performance - Building on the Principles for Enhancing Professionalism. Pocket handbook of the Institute of Nuclear Power Operations, 1997 September.

5. T. Long and E. Davey. Darlington Annunciation: User Information Needs, Current Experience and Improvement Priorities. Paper presented at the International Atomic Energy Agency Specialist Meeting on 'Experience and Improvements in Advanced Alarm Annunciation Systems in Nuclear Power Plants', Chalk River, Ontario, 1996 September 17-19.