ABSTRACT

Several nuclear power plants in the United States are starting instrumentation and control (I&C) modernization programs using digital equipment to address obsolescence issues and the need to improve plant performance while maintaining high levels of safety. As an integral part of the I&C modernization program at a nuclear power plant, the control room and other human-system interfaces (HSIs) are also being modernized. To support safe and effective operation, it is critical to plan, design, implement, train for, operate, and maintain the control room and HSI changes to take advantage of human cognitive processing abilities.

A project, jointly funded by the Electric Power Research Institute (EPRI) and the United States Department of Energy (DOE) under the Nuclear Energy Plant Optimization (NEPO) Program, is developing guidance for specifying and designing control rooms, remote shut-down panels, HSIs etc. The guidance is intended for application by utilities and suppliers of control room and HSI modernization. The guidance will facilitate specification, design, implementation, operations, maintenance, training, and licensing activities. This guidance will be used to reduce the likelihood of human errors and licensing risk, to gain maximum benefit of implemented technology, and to increase performance. The guidance is of five types. The first is planning guidance to help a utility develop its plant-specific control room operating concepts, its plant-specific endpoint vision for the control room, its migration path to achieve that endpoint vision, and its regulatory, licensing, and human factors program plans. The second is process guidance for general HSI design and integration, human factors engineering analyses, verification and validation, in-service monitoring processes, etc. The third is detailed human factors engineering guidance for control room and HSI technical areas. The fourth is guidance for licensing. The fifth is guidance for special topics related to operations and maintenance including training and simulation and safety monitoring and control guidance. Currently, the plan is that the overall guidelines will be made up of 34 guidelines on different topics of which 31 are completed. This may increase based on input from the project working group which includes 21 utilities as well as nuclear utility industry participants.

INTRODUCTION

The majority of instrumentation and control (I&C) equipment in nuclear power plants in the United States was designed at least 25 to 45 years ago with analog and relay components, and in some cases rudimentary digital technology. Today, most of these plants continue to operate with a substantial amount of this original I&C equipment that
is or soon will be obsolete. Much of this equipment is approaching or exceeding its life expectancy, resulting in increasing maintenance efforts to sustain acceptable system performance. Decreasing availability of replacement parts, and the accelerating deterioration of the infrastructure of manufacturers that support analog technology, accentuate the obsolescence problems and cause operation and maintenance (O&M) cost increases. In addition, the older technology limits the possibilities for adding new beneficial capabilities to the plant systems and interfaces.

Modernization of I&C systems and components, using digital equipment to address these obsolescence issues and the need to improve plant performance (e.g., increase power output capacity, reliability, and availability) while maintaining high levels of safety, is a current major issue for nuclear power plants in the United States and throughout the world. A number of nuclear power utilities are committing to major modernization programs. The need for this modernization will accelerate as plants age, as obsolescence issues increase, as more plants receive their license renewals, and as features that digital technology offers are needed to increase cost-effective electricity production. As an integral part of the I&C modernization program at a nuclear power plant, the control room and other human-system interfaces (HSIs) will also be modernized. To support safe and effective operation, it is critical to specify, design, implement, operate, and maintain, as well as train for, the control room and HSI changes to take advantage of human cognitive processing abilities. This consideration of the human should be done to increase performance and to reduce the likelihood of human errors. This is essential in order to obtain maximum benefits of the new technology.

In most cases, modernized control rooms will be the result of incremental modernization steps of equipment and HSIs over several fuel cycle outages. The resulting control room and HSIs at each of the incremental modernization steps will be a hybrid control room. That is, it will be a combination of analog and digital technology. After each modernization step, the amount of analog technology will decrease and the amount of digital technology will increase. This means that the relationship between the human and the control room technology will keep changing until the complete modernization program is completed. Depending on how far the plant wants to go with its modernization program, the final configuration of the control room may still be a hybrid configuration. It should also be noted that even if the plant decides to do its entire modernization at once, the resultant control room could still be hybrid if that is the desired final state.

Concern exists by the nuclear plants that if new digital equipment and the resulting control rooms and HSIs are not specified, designed, implemented, operated, and maintained correctly from a human factors perspective, the potential for human errors will increase and benefits of the new technology will not be achieved. It is important that a vision of the final configuration of the control room is established at the beginning of the modernization program and that current human factors knowledge and guidance is used in reaching that configuration. It is also important that the human factors knowledge and guidance is applied to each modernization step of the control room and HSIs as well as to the final configuration of the control room and HSIs. It is also
important that the control room and interfaces at the end of each step are totally capable of controlling the plant under all conditions, and potentially for the rest of the life of the plant. This last is essential in case funding or other conditions occur that eliminate or significantly delay future modernization steps.

Examples of some of the major control room questions being asked by the plants are the following:

- What changes to our concept of operations should we consider?
- What new functional and HSI capabilities should we consider?
- How should we incorporate human factors engineering concepts?
- How do we reduce the likelihood of human errors?
- How do we achieve the full benefits from the new digital technology?
- How do we train operators during the on-going changes in the control room?
- When, where, and to what extent should we use automation, computerized procedures, computerized support systems, etc.?
- What are the best types of displays available for various applications?
- What are the required licensing and regulatory activities and how do we ensure regulatory acceptance?

Although numerous human factors guidelines have been published, specific guidance needed both to satisfy safety requirements and to achieve high levels of availability, reliability, and productivity in nuclear power plants is not readily available. The United States Nuclear Regulatory Commission (NRC) has published human factors guidance documents in some related areas that are intended for use by the NRC in reviewing proposed upgrades regarding safety issues. They do not provide additional guidance needed to specify, design, implement, operate, maintain, and train for cost-effective, integrated HSIs to achieve high levels of availability, reliability, and productivity. Nuclear utilities are looking for guidelines to address the areas above for operating plants. A scoping and planning study for a project to develop these guidelines was done in the latter part of 2000 [1].

**ENDPOINT VISION AND MIGRATION PATH DEFINITION**

Nuclear utilities have also identified a need for a process to determine the plant-specific vision for the control room at the end of the modernization program. This endpoint vision includes the role of operator, the type of interfaces, and the functionality of the systems and interfaces in the control room. An important aspect in the definition of what should be in the control room and how it is implemented is the concept of operations that includes how the plant will be operated under normal conditions and abnormal conditions, including loss of displays, loss of controls, and loss of plant systems and equipment.

In the United States it is extremely unlikely that a nuclear power plant will shut down long enough in a single outage to do a complete modernization of the control room, HSIs, and I&C needed to reach the plant’s endpoint vision for the control room, HSIs, and I&C systems and components. This is true in other countries as well. The nuclear plants are
reducing the duration of refueling outages in the plants to increase availability and power production. They are requiring that the modernization activities do not extend the planned refueling outage duration. The exception to do a complete modernization in one outage would be for a plant that is only going to do a minor modernization program that can be done within one normal refueling outage, or a plant that is planning an extended outage for other reasons and can use that as an opportunity to modernize. Therefore, another important process that is needed is how to develop a plant-specific migration strategy to achieve the control room endpoint vision over several modernization steps. This migration plan, as well as the control room endpoint vision, needs to be correlated with the overall plant-specific I&C endpoint vision and migration path and will mostly likely require some level of iteration. Again, it is important to make sure in the migration plans that the plant and control room configuration at the end of each step can completely handle the plant under normal and abnormal conditions. Although the intent is to complete the modernization program, conditions may change and the remaining part of the modernization program may not be able to be done. Therefore, each step should leave the plant in a state that it could be operated indefinitely.

CONTROL ROOM AND HSI GUIDELINE DEVELOPMENT

The Electric Power Research Institute (EPRI) and the United States Department of Energy (DOE) have an on-going project started in 2001 to develop guidance, and the technical bases for the guidance, for control rooms and digital HSI including human performance related issues. This guidance will support, in addition to meeting safety requirements and the plant's operational requirements, improved cost-effective plant and human performance and reduced likelihood of human errors, resulting in improved plant safety, availability, reliability, and cost-effective operation. This project is also developing technical bases to support the development of design and implementation guidance in new critical advanced technology areas related to control rooms, such as process automation and computerized operator support systems. Although the guidelines are being developed with modernization of control rooms in mind, the majority of the guidance applies to the design of new plant digital control rooms as well.

The guidance being developed in this project is of five types. The first is planning guidance to help a utility develop its plant-specific control room operating concepts, its plant-specific endpoint vision for the control room, its migration path to achieve that endpoint vision, and its regulatory, licensing, and human factors program plans. The planning guidelines for operating concepts, endpoint vision, and migration path have been developed and published [2]. The second is process guidance for general HSI design and integration, human factors engineering analyses, verification and validation, in-service monitoring processes, etc. The third is detailed human factors engineering guidance for control room and HSI technical areas. The fourth is guidance for licensing. The fifth is guidance for special topics related to operations and maintenance including training and simulation and safety monitoring and control guidance. Currently, the plan is that the overall guidelines will be made up of 34 guidelines on different topics of which 31 are completed.
A working group of industry experts representing 21 nuclear utilities, 4 suppliers, consultants, Brookhaven National Laboratory (BNL), DOE, EPRI, Halden Reactor Project, Nuclear Energy Institute (NEI), and NRC Research and Regulation Branches was put together to identify what guidance is needed, to prioritize development activities, to provide input, and to review and evaluate the resultant guidelines and technical bases behind them.

Since several plants are already starting comprehensive I&C modernization programs, the need for guidance in many areas, including the endpoint vision definition and migration plan, is urgent. Therefore, the plants cannot wait for the completion of the project for the guidance. To support this need, intermediate guidance results are being issued throughout the project based on the identified needs of the nuclear utilities in the working group [2, 3, 4, 5]. In addition to published reports, drafts of guidance and technical bases are being released to the working group members as they are developed.

**CRITICAL GOALS**

Modern technology, with its ability to better provide and use real-time information, offers the opportunity to improve productivity and to replace systems that are unreliable, obsolete, and costly to operate and maintain. Some of the critical goals for nuclear power plants are the following:

- Maximize plant capacity/output power levels,
- Achieve and maintain high reliability,
- Achieve and maintain high availability,
- Maintain high levels of safety,
- Maintain high levels of operator awareness of the plant and equipment states,
- Minimize the likelihood of human errors, and
- Integrate fault tolerance and fault recovery into the systems (both from potential human and equipment errors).

Modern control room, HSI, and I&C technology can provide significant tools to meet the above critical goals. Therefore, the guidance for control rooms and digital HSI developed in this project will support achieving the critical goals for the plants.

**CONTROL ROOM ENDPOINT DEFINITION AND MODERN TECHNOLOGY**

A major aspect of the endpoint vision of the control room is the determination of the capability/functionality of the systems and interfaces. In the past, nuclear power plants had commonly looked at “like-for-like” replacements when they start defining the modernization of old systems. That is, the plants just implement the same functionality and capability of the old system with new technology. At the most, some simple interface or other minor changes may be made. This may be the best modernization solution in some cases. However, in many/most cases it is not. Therefore, it is important to look at and take advantage of the improvements that modern, digital technology can bring now and in the foreseeable future.
As part of the definition of the endpoint vision of the control room and HSIs, it is important to consider what the new technology offers, how it can be used, and what the benefits and drawbacks of the new technology are. Some of the areas that should be considered include the following:

- Large screen displays,
- Video display unit (VDU) based information systems,
- Soft controls,
- On-line, computerized procedures,
- Advanced alarm processing and presentation techniques,
- Model- and task-based displays,
- Interface management strategies, including navigation,
- Computer-supported information collection, access, manipulation, distribution, storage, and documentation,
- Integrated displays (e.g., procedure displays that include process information and soft controls),
- Self-testing and diagnostics,
- Redundancy and diversity,
- On-line monitoring and diagnostics,
- Early fault detection and diagnostics,
- Fault tolerance and fault recovery,
- Process automation,
- Computerized operator support systems and decision aids,
- Maintenance aids, and
- Engineering aids.

Consideration should be given to the full spectrum of operational and maintenance activities under normal and abnormal conditions.

While the main thrust of this project has been the modernization of the control rooms in operating nuclear power plants, many of the same considerations for defining the endpoint vision apply to the design of new plants. The major differences are that the starting point for a new plant is a blank sheet, as opposed to an existing control room, and that the new plant control room will be implemented all at one time, as opposed to a migration program over several outages. Another major difference is that the new plant can easily implement the entire infrastructure needed to support the control room, whereas in the operating plants there will be more limitations. These limitations will either have to be worked around or they will eliminate some of the possibilities in the control room and HSIs.

**CURRENT STATUS**

The guidelines are currently being developed with most of them completed at this time. This means that they have been written, reviewed by the entire development team, had comments by the development team resolved, reviewed by the working, and had comments by the working group resolved. They will be published by the end of 2004.
Additional information is expected to be added to the guidelines in the future based on plant use of the guidelines. The 34 guideline sections (not counting the introduction) and current status are given below.

- **Introduction** (background, objectives and scope, general purposes of human factors engineering, intended users) – complete *

- **Planning**
  - Management considerations – complete *
  - Endpoint definition – complete *
  - Migration strategy – complete *
  - Human factors program planning – complete
  - Planning for regulatory and licensing activities – complete

- **Process**
  - HFE in the design process – complete
  - Operating experience review – complete
  - Function analysis and allocation – complete
  - Task analysis – complete
  - Staffing, qualifications, and integrated work design – complete
  - Human error analysis – complete
  - Human-system interface and procedure design – complete
  - HFE verification and validation – complete
  - In-service monitoring – complete
  - Methods and tools for collecting information from users – complete

- **Detailed human factors engineering guidelines**
  - Information display – complete *
  - User interface interaction and management – complete
  - Soft control systems – complete *
  - Alarm systems – complete *
  - Computer-based procedure systems – complete *
  - Computerized operator support systems – complete
  - Communications systems – complete
  - Workstations and workplaces – complete

- **Licensing**
  - Regulatory requirements and expectations – complete
  - Engineering evaluations related to licensing – complete
  - 10 CFR 50.59 evaluations – complete
  - Licensing submittals – complete

- **Special topics related to operations and maintenance**
  - Maintainability of digital systems – complete
  - Configuration management and security – complete
Training considerations unique to digital I&C modernization programs – complete
Safety monitoring and control in modernized control rooms – complete
Operations under degraded I&C/HSI and plant system conditions – new
Automation and dynamic smart control room procedures – new
Control spaces outside MCR – new

The guidelines that fall in the complete category and have been marked with an asterisk have been published in an earlier version as an interim report [3] so that they are available for use by plant owners/operators and vendors/suppliers. A report with all of the completed guidelines will be published at the end of the year [6].

7. RELATED ACTIVITIES

The working group and development team identified the current set of guidelines that are being addressed under this project. However, it is clear that there are other areas of concern that need guidance and technical basis development. The working group and development team put together a list of 20 topic areas. Several experts reviewed this list and ranked the topics using four criteria:
• Potential impact on productivity and cost
• Safety impact
• Scope which refers to whether it applies to a large number of plants or not
• Urgency

The topic areas and the results of the ranking have been described [7].

A workshop on control room modernization was developed and presented at the IEEE 7th Conference on Human Factors and Power Plants. The technical material used for the workshop was published for broader dissemination [8].

8. CONCLUSIONS

Obsolescence issues with existing I&C equipment and the need to improve plant performance is leading to modernization of I&C systems and components, including control rooms and HSIs, in nuclear power plants. These modernization programs offer the opportunity to take maximum advantage of modern technology to help achieve new, more aggressive plant goals. Concern exists that, if the new digital technology is not specified, designed, implemented, operated, maintained, and properly trained for, the potential for human errors will increase and the benefits of the new technology will not be achieved. The guidance being developed by EPRI and DOE will help minimize this concern. Most of the guidance being developed will support new plant control room and HSI design as well as to the modernization of operating plants.
REFERENCES


