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Local Control Stations: Human Engineering Issues and Insights

Prepared by
W. S. Brown, J. C. Higgins, J. M. O'Hara

Brookhaven National Laboratory

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Prepared by
W. S. Brown, J. C. Higgins, J. M. O'Hara

Brookhaven National Laboratory
Upton, NY 11973-5000

Prepared for
Division of Systems Research
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
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ABSTRACT

The objective of this research project was to evaluate current human engineering at local control stations (LCSs) in nuclear power plants, and to identify good human engineering practices relevant to the design of these operator interfaces. General literature and reports of operating experience were reviewed to determine the extent and type of human engineering deficiencies at LCSs in nuclear power plants. In-plant assessments were made of human engineering at single-function as well as multifunction LCSs. Besides confirming the existence of human engineering deficiencies at LCSs, the in-plant assessments provided information about the human engineering upgrades that have been made at nuclear power plants. Upgrades were typically the result of any of three influences - regulatory activity, broad industry initiatives such as INPO, and specific in-plant programs (e.g., activities related to training). It is concluded that the quality of LCSs is quite variable and might be improved if there were greater awareness of good practices and existing human engineering guidance relevant to these operator interfaces, which is available from a variety of sources. To make such human engineering guidance more readily accessible, guidelines were compiled from such sources and included in the report as an appendix.

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EXECUTIVE SUMMARY

The objective of this project was to evaluate current human engineering at LCSs in nuclear power plants, and to identify good human engineering practices relevant to the design of LCSs. Two types of LCS were identified. A *multifunction* LCS was defined as any operator interface related to plant process control, not located in the control room and not consisting solely of manually-operated valves or circuit breakers. A *single-function* LCS was defined as any operator interface related to plant process control that is not located in the control room and is not a multifunction panel; this category includes all controls (valves, switches, breakers) and displays (meters, gauges, monitors) that are operated or consulted during normal, abnormal, or emergency operations. Equipment that is operated or consulted *only* during maintenance was excluded.

General literature and reports of operating experience were reviewed to determine the extent and type of human engineering deficiencies at local control stations in nuclear power plants. A review of the NRC and industry literature identified three issues related to human engineering at LCSs: wrong unit/wrong train events; inadequate indication of the position of manual valves; and maintainability problems. Reports of plant experience were reviewed to determine the specific nature of human engineering deficiencies at LCSs in plants, and to determine the types of problems caused by these deficiencies. Descriptions of deficiencies were tabulated for two sources: NRC Emergency Operating Procedure inspection reports and Licensee Event Reports. The review suggested that deficiencies at LCSs are somewhat common across the industry and can have potentially significant consequences.

In-plant assessments were made of human engineering at single-function as well as multifunction LCSs. Eleven plants participated in these assessments; the plants were chosen to represent the commercial nuclear power industry with respect to both plant vendor and age. More than 100 LCSs were assessed at these 11 plants. The assessments indicated that the design of both multifunction and single-function LCSs was highly variable both within and between plants. Some of the variation can be attributed to the lack of a systematic design approach and specific guidelines for LCSs.

Besides confirming the existence of human engineering deficiencies at LCSs, the in-plant assessments provided information about the human engineering upgrades that have been made to LCSs at nuclear power plants. Upgrades were typically the result of any of three influences - regulatory activity, broad industry initiatives such as by INPO, and specific in-plant programs. While all these factors have undoubtedly mitigated human engineering deficiencies at many operator interfaces, many LCSs remain deficient. Thus, the overall results of efforts to improve human engineering outside the control room have been uneven, and many of the same types of deficiencies noted in the early 1980s continue to exist.

The results have implications for current practice and for future plant designs. It is concluded that the quality of LCSs might be improved if there were greater awareness of good practices and existing human engineering guidance on these operator interfaces, which is available from a variety of sources. To make such human engineering guidance more readily accessible, guidelines were compiled from such sources and included in the report as an appendix. It was noted during site visits that while human engineering upgrades (improved lighting, labeling, position indication) often had

been performed at EOP-related equipment, other risk-significant components, i.e., important manual valves, had not received such attention. Finally, the costs of backfitting human engineering improvements can be high as compared with the costs of including such enhancements in the original design.

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ACRONYMS

AFW	auxiliary feedwater
BWR	boiling water reactor
BWST	borated water storage tank
CCW	component cooling water
CS	core spray
ECW	emergency cooling water
EDG	emergency diesel generator
EFW	emergency feedwater
EOP	emergency operating procedure
EPRI	Electric Power Research Institute
HPCS	high pressure core spray
HPI	high pressure injection
IMV	important manual valve
INPO	Institute of Nuclear Power Operations
LCS	local control station
LER	licensee event report
LPCI	low pressure coolant injection
LPI	low pressure injection
NRC	U.S. Nuclear Regulatory Commission
PRA	probabilistic risk assessment
PWR	pressurized water reactor
RCIC	reactor core isolation cooling
RHR	residual heat removal
RWST	refueling water storage tank
SCSS	Sequence Coding and Search System
SI	safety injection
SRP	Standard Review Plan
SW	service water
WBGT	wet-bulb globe temperature

1.0 INTRODUCTION

1.1 Background

The U.S. Nuclear Regulatory Commission (NRC) developed "Guidelines for Control Room Design Reviews," (NUREG-0700) to provide guidance on the human factors aspects of control room design, and it is widely used as a basis for evaluating human factors as part of detailed reviews of these designs. However, these guidelines have not been applied consistently to operator interfaces located outside the main control room [i.e., local control stations (LCSs)]. At many of these LCSs, operators must take action during normal, abnormal, and emergency operations. Errors at LCSs have initiated and exacerbated off-normal events. Therefore, human engineering of these operator interfaces is important to the NRC.

Human engineering deficiencies at LCSs were documented in a study by Hartley, Levy, and Fecht (1984) who noted that human factors deficiencies at safety significant LCSs increase "the potential for operator errors that could be detrimental to plant and public safety." They reported that most if not all of the LCSs that they evaluated exhibited violations of the human engineering principles presented in NUREG-0700, NRC contractor reports and documents produced by the Electric Power Research Institute (EPRI). Labeling practices and component design that did not comply with the human engineering guidance available at the time were common.

More recently, as part of an evaluation of the effects of LCS design on plant risk, O'Hara et al. (1990) evaluated multifunction panels at four plants. They concluded, as had Hartley et al., that the "design of LCS panels is highly variable both within and across [plants]." They attributed some of the variation to the lack of a systematic approach to LCS design - particularly the fact that "the LCSs were not typically designed and integrated into the plant at one time." Many remote shutdown panels, for example, were retrofitted to satisfy 10 CFR 50 Appendix R requirements. O'Hara et al. also pointed to the lack of applicable design guidance as a cause of the variations observed.

The research to be described in this report expanded the scope of operator interfaces to be considered to single-function as well as multifunction LCSs, and sought to identify good human engineering practices in addition to documenting deficiencies. Portions of this research have been described in Brookhaven National Laboratory technical reports by Ruger, Brown, and Higgins (1991), and Brown and Higgins (1992).

1.2 Objective

The objective of this project was to consider the effects of human engineering at LCSs in nuclear power plants, and to identify good human engineering practices relevant to the design of LCSs. To this end, the following efforts were undertaken:

- examination of literature and operating experience related to human engineering at LCSs
- documentation of current human engineering practices at LCSs
- compilation of human engineering guidance relevant to LCSs

1.3 Approach

Section 2 covers the assessment of human engineering at LCSs. The assessment encompassed (1) a review of LCS operating experience at nuclear power plants as documented in various sources, and (2) in-plant assessments of operator interfaces outside the control room. These efforts are described in Sections 2.2 and 2.3, respectively. Conclusions based on the review of operating experience and in-plant assessments are described in Section 2.4. Section 3 gives the conclusions relevant to both current practice and future plants. Human engineering guidance relevant to LCSs is compiled in Appendix D.

2.0 ASSESSMENT OF HUMAN ENGINEERING AT LCSs

2.1 Definition of LCS Categories

Before attempting to assess human engineering at LCSs, it was necessary to specify the types of operator interfaces to be considered. Hartley et al. (1984) identified three types: integrated multifunction control panels, single-function manual switches, and single-function manual valves. In the present study, a similar distinction is made between local control panels and single components; two types of LCS are identified. A *multifunction* LCS is defined as any operator interface related to process control not located in the control room and not consisting solely of manually-operated valves or circuit breakers. This definition encompasses the same types of interfaces as the "integrated multifunction control panels" identified by Hartley et al. (1984), e.g., remote shutdown panels and diesel generator panels. A *single-function* LCS is defined as any operator interface related to plant process control that is not located in the control room and is not a multifunction panel; this category includes all controls (valves, switches, breakers) and displays (meters, gauges, monitors) operated or consulted during normal, abnormal, or emergency operations. Most equipment operated or consulted *only* during maintenance was excluded from consideration, since the contribution of such equipment to risk is relatively small. The exceptions were certain manually operated valves (e.g., pump suction and discharge valves, component cooling water isolation valves) which, if mispositioned, can contribute significantly to risk. These valves were considered in the study (see Section 2.3.1).

Using the LCS evaluations documented by Hartley et al. (1984) as a foundation, a further assessment of LCSs was undertaken to identify the types of human engineering deficiencies in commercial nuclear power plants.

2.2 Review of Relevant Documents

2.2.1 General Literature

A review of the NRC and industry literature identified three LCS-related issues: actions performed on the wrong unit, train, or component; inadequate indication of the position of manual valves; and maintainability.

Wrong Unit/Train/Component Events. Events involving wrong unit/wrong train errors were the subject of NRC Information Notices and Office for the Analysis and Evaluation of Operational Data reports and memoranda during the mid-1980s. Persinko and Ramey-Smith (1986) investigated events that resulted from actions being performed on the wrong train of systems with redundant trains, or on the wrong unit of a multi-unit facility. The investigation also included events in which the wrong component was operated; these events were found to be associated with the same factors as wrong unit/wrong train events. Among the contributing factors identified were labeling, layout/equipment design, communications, and environmental factors such as high temperature and cramped surroundings. Inadequate labeling was either a primary or secondary contributor to 19 of the 35 events reviewed, more than any other contributor. Among the labeling deficiencies noted during plant walk-throughs were:

- inconsistent nomenclature, abbreviations, and numbering
- lack of a program to replace missing or damaged labels
- replacement of illegible tags with labels that were only marginally more readable

It was noted that some utilities were attempting to identify labeling materials and practices that were appropriate for nuclear power plants and that conformed to the human engineering guidance available at the time (e.g., EPRI-NP-4350). However, the authors concluded from site visits that there was apparently "...little communication...between utilities and even within the same utility on this topic..."

Seminara (1988) considered 220 events (reported between 1981 and 1986) involving misidentification of unit, train, or component. Roughly 45 percent of the events involved incorrectly identified components; misidentification of train accounted for 25 percent. The most frequently misidentified components were valves (30 percent), breakers (28 percent), and fuses (11 percent). Table 1 summarizes the numbers and types of personnel involved in the misidentification errors. Seminara concluded that "...non-licensed operators might best be targeted for training relating to error-free identification of plant facilities, equipment, and components..." However, these data may also indicate that human engineering (especially labeling) outside the control room is poor, since the bulk of the errors were committed by personnel who perform their functions out in the plant.

Table 1. Personnel Involved in Incorrect Identification of Unit, Train, Channel, or Component (data summarized from Seminara, 1988)

Operators	**99**
Licensed	36
Non-Licensed	60
Other	3
Technicians	79
I&C	49
Test Technicians	17
Other	13
Maintenance	**26**
Miscellaneous	**18**

Inadequate Indication of Valve Position. Lewis et al. (1984) discussed problems associated with inadequate indication of the status of components (especially valves) in the context of monitoring the status of safety systems. Incorrect assessment of the position of a valve can result from deficiencies in its design, such as unusual or awkward orientation of the valve, faulty assembly of the position indicator, or a handwheel which operates contrary to convention. The authors cited an event in which containment spray isolation valves were assumed to be locked open when they were, in fact, closed. The status of the valves had been inferred from the appearance of the valve stems, which were 6 inches longer than is typical.

Maintainability. Most maintenance activities take place outside the control room. Therefore, human engineering considerations pertaining to maintainability (e.g., labeling, lighting, accessibility) are often applicable to LCSs. Seminara et al. (1980) reviewed human factors in power plant maintainability.

Among the areas of concern identified in their report were:

- poor labeling of equipment
- lack of coding to differentiate components; e.g., systems or units
- inaccessibility of components
- "hostile" environments; e.g., extreme heat, noise, slippery surfaces, or poor illumination
- inadequate communications systems coverage

2.2.2 Reports of Plant Experience

Reports of plant experience were reviewed to determine the extent and type of human engineering deficiencies at LCSs in actual plants, and to determine the types of problems caused by these deficiencies. Two sources of information were reviewed: NRC Emergency Operating Procedure (EOP) inspection reports and Licensee Event Reports (LERs). Participants in EOP inspections also were interviewed. Events and observations were selected emphasizing the significance of their effects on plant systems. Appendix A gives examples according to the categories of human engineering deficiencies that emerged from the general literature review described in the previous section; the tabulation provides some representative examples of the types of human factors inadequacies and the significance of the events they have caused. Many additional events were identified which may have been caused by inadequate human engineering (e.g., operation of a valve in the wrong train), but were not included because the source document did not attribute any specific cause other than human error to the event. Thus, no clear determination could be made of the status of the human-system interface, and whether it contributed to the error. In the sections to follow, the methods used to investigate each source of operating experience are described and general findings are outlined.

Inspection Reports: Emergency Operating Procedures

The purpose of EOP inspections is to verify that the EOPs are technically accurate, that required actions can be accomplished using existing equipment, controls, and instrumentation, and that the procedures are usable by operating personnel. The evaluations include a human factors analysis of all EOP-related elements. During the inspection, walkdowns of EOPs allow EOP-related operator interfaces to be assessed. Since EOPs typically include operator activities at LCSs, the inspection reports often provide data on human engineering deficiencies at LCSs. These deficiencies are notable, because they occur at equipment used under emergency conditions.

Reports of inspections made in 1988 and 1990 were reviewed and descriptions noted of human engineering deficiencies at LCSs. (The reports reviewed are listed in Appendix B.) Most deficiencies could be placed in one of the following five general categories:

- ***Labeling*** refers to identification of equipment and controls. Poor labels are poorly positioned, not securely attached, handwritten, lacking in contrast, or missing needed information; good labels are permanent, legible, informative (describing the component's function, inputs, outputs, capacity), and coded to support rapid and reliable identification of components.

- ***Indication*** pertains to the ease of ascertaining the state of a valve or breaker (e.g., open/closed, energized/de-energized) or to the clarity of information conveyed by meters or gauges. Examples of poor indications include the lack of a means of locally determining the state of the equipment, the use of inconsistent units or scales on meters

or gauges, and instruments that are difficult to read. Conversely, an LCS with good indication might have a local positive indication of state of the equipment and contain instrumentation with consistent scales.

- ***Control*** refers to the operation of equipment (as opposed to the identification or status of that equipment). Poor controls might operate in a manner inconsistent with an operator's expectation based on population stereotypes or other controls of its type in the plant, and might be subject to inadvertent operation or require excessive force. Good controls are consistent, and grouped or coded (color, shape) according to function.

- ***Environment*** encompasses issues of lighting, noise, temperature and humidity, and physical access to equipment. A poor environment is one in which lighting is inadequate for the task to be performed, where continued presence at the station subjects the operator to discomfort or risk (due, e.g., to heat, noise, or radiation), or where the location of equipment requires unsafe or uncomfortable working postures.

- ***Communication*** concerns the exchange of information with others either nearby or in other areas of the plant, e.g., the control room. For example, communication could be considered poor if the paging system is inadequate, if headsets are unavailable or difficult to use, or if the use of radios is precluded in the area of the LCS.

The types of deficiencies noted in each report are summarized in Table 2 and Table 3 for 1988 and 1990, respectively. The reports of deficiencies differed from plant to plant. Some reports individually enumerated multiple deficiencies of a given type, while others cited a general inadequacy in a certain area, and some did not detail all of the deficiencies found at LCSs, but instead, documented only representative deficiencies. Therefore, no attempt was made to analyze the reports quantitatively; i.e., the frequencies with which the categories of deficiencies occurred were not recorded. Given this limitation, the relative prevalence of the type of human engineering deficiencies does appear similar in the two samples, and it can be concluded that inadequate labeling and poor environmental conditions are common at LCSs.

To better define LCS deficiencies, a meeting was held with NRC and contractor members of EOP inspection teams to discuss problems typical of each category of LCS human engineering deficiency. Rough estimates of the prevalence of human engineering deficiencies at LCSs, based on the teams' experience, agreed with the conclusion of the EOP survey. According to the team, most plants had one or more deficiencies in labeling or indication at EOP-related LCSs. Deficiencies in communication facilities and environmental conditions (especially inaccessibility of equipment and lack of adequate emergency lighting) were commonly encountered. Poor control interfaces were slightly less prevalent.

Licensee Event Reports

Licensee Event Reports (LERs) from a three-year span (1987, 1988, and 1989) were reviewed for incidents pertaining to human engineering deficiencies at LCSs. LERs with the following Sequence Coding and Search System (SCSS) watch list codes were considered:

038 Poor Ergonomics or Human Environment
032 Communication Problem
035 Human Error

Table 2. Human Engineering Deficiencies Noted in Emergency Operating Procedure Inspection Reports (1988 sample)

Docket No.	Facility/Unit	Labeling[1]	Indication[2]	Control[3]	Environment[4]	Communic.[5]
220/88-22 410/88-23	Nine Mile Point 1	X	X	X	X	X
237/88-12 249/88-14	Dresden 2 Dresden 3	X				
247/88-15	Indian Point 2					
282/88-10 306/88-10	Prairie Island 1 Prairie Island 2	X			X	X
302/88-09	Crystal River 3	X	X			
313/88-17	Arkansas Nuclear 1	X				
315/88-015 316/88-017	D.C. Cook 1 D.C. Cook 2	X				
321/88-12 366/88-12	Hatch 1 Hatch 2					
333/88-200	Fitzpatrick	X				
335/88-08 389/88-08	St.Lucie 1 St.Lucie 2	X			X	X
336/88-10	Millstone 2	X	X		X	X
344/88-23	Trojan				X	
361/88-13 362/88-14	San Onofre 2 San Onofre 3	X	X		X	
382/88-18	Waterford 3	X	X		X	
416/88-06	Grand Gulf 1	X		X	X	
482/88-13	Wolf Creek 1	X	X		X	X

1 Labeling refers to identification of equipment and controls.

2 Indication pertains to the ease of ascertaining the state of a valve or breaker (e.g., open/closed, energized/de-energized) or to the clarity of information conveyed by meters or gauges.

3 Control refers to the operation of equipment (as opposed to the identification or status of that equipment).

4 Environment encompasses issues of lighting, noise, temperature and humidity, and physical access to equipment.

5 Communication refers to the need for and support of the exchange of information between local operators and personnel elsewhere in the plant.

Table 3. Human Engineering Deficiencies Noted in Emergency Operating Procedure Inspection Reports (1990 sample)

Docket No.	Facility/Unit	Labeling[1]	Indication[2]	Control[3]	Environment[4]	Communic.[5]
155/90-008	Big Rock Point					
313/90-01 368/90-01	Arkansas Nuclear One 2		X		X	
344/90-80 412/90-80	Beaver Valley 1 Beaver Valley 2	X	X		X	
272/90-80 311/90-80	Salem 1 Salem 2	X			X	
280/90-09 281/90-09	Surry 1 Surry 2	X	X	X	X	X
295/90-004 304/90-004	Zion 1 Zion 2	X			X	
348/90-02 364/90-02	Farley 1 Farley 2	X	X	X	X	
352/90-80 353/90-80	Limerick 1 Limerick 2	X				
354/90-18	Hope Creek 1				X	
387/90-80 388/90-80	Susquehanna 1 Susquehanna 2		X		X	
395/90-23	Summer	X			X	
397/90-20	WPPSS 2	X		X	X	
424/90-08 425/90-08	Vogtle 1 Vogtle 2	X	X		X	
443/90-84	Seabrook 1	X			X	
458/90-07	River Bend 1	X			X	

1 Labeling refers to identification of equipment and controls.

2 Indication pertains to the ease of ascertaining the state of a valve or breaker (e.g., open/closed, energized/de-energized) or to the clarity of information conveyed by meters or gauges.

3 Control refers to the operation of equipment (as opposed to the identification or status of that equipment).

4 Environment encompasses issues of lighting, noise, temperature and humidity, and physical access to equipment.

5 Communication refers to the need for and support of the exchange of information between local operators and personnel elsewhere in the plant.

About 3,000 LERs resulted from this selection. LERs coded as involving "poor ergonomics or human environment" (of which there were about 25 per year) were reviewed individually for references to human engineering deficiencies at LCSs. Many events were identified as having occurred outside the control room as a result of a specific human interface deficiency. The events typically pertained to labeling and environment, notably problems with physical accessibility of equipment. However, roughly half of these events occurred at equipment used only for testing or calibration. Some of this equipment (e.g., terminal blocks inside electrical panels) falls outside our definition of LCS.

From a sample of the roughly 125 LERs coded as a "communication problem," it was concluded that these typically refer to failures of procedural or administrative communications. The causes of miscommunication among operators are not usually specified, so that the deficiency in the means of communication or the environment cannot be inferred.

Over 2,000 abstracts of LERs coded "human error" were searched using key words pertaining to incorrect human actions and to the classes of human engineering deficiency identified previously. In many reports, the incorrect local action was attributed to lack of attention to detail by personnel. Although it is not unreasonable to infer that less-than-optimal human engineering contributed to many of these errors, the examples in Appendix A were chosen only from LERs that cited specific local human engineering deficiencies as a contributing cause, or mentioned improvements at the LCS as a means of preventing recurrence.

A comprehensive review of all LERs from January 1991 (NUREG-2000) identified 14 events (out of 183 LERs) involving human engineering deficiencies at LCSs, indicating that reportable events continued to occur as a consequence of LCS deficiencies beyond the selected three-year span.

2.3 In-Plant Assessment of LCSs

From June 1991 to January 1992, in-plant assessments were made of human engineering at single-function as well as multifunction LCSs. Eleven plants participated in these assessments; the plants were chosen to represent the commercial nuclear power industry with respect to both plant vendor and age. About ten LCSs were assessed at each of these plants.

2.3.1 Procedure

Preparation

Two researchers visited each plant; one person was a human factors specialist, and the other was experienced in nuclear power plant operation and inspection. The variety of plant types in the sample and the diversity of LCSs between plants made it impossible to identify in advance a standard group of LCSs to be examined in each plant visited. Nevertheless, it was desirable to ensure that the LCSs examined (1) included a broad range of plant equipment and required local operator actions, (2) did not represent only those areas chosen by plant personnel, and (3) were comparable, in some way, across plants. Therefore, the identification of LCSs to be assessed was guided by reference to two plant operating procedures: shutdown from outside the control room, and station blackout (SBO). (The host utilities provided information copies of the relevant procedures to the researchers before the site visit.) These procedures were chosen because they were expected to contain the greatest number and variety of local operator actions, and because emergency lighting (which EOP inspection teams identified as problematic) would be required at the locations at which the actions were performed. The use of

procedures not only identified the LCSs to be observed, but also revealed the details and context of operator actions required at the station. During the assessment, other nearby LCSs were also observed. In addition, an effort was made to examine important manual valves, selected by a risk-based approach. Five separate boiling water reactor (BWR) probabilistic risk assessments (PRAs) and five pressurized water reactor (PWR) PRAs were used in determining those manual valves most important to risk (Table 4). Various documents were used for the determination, including the PRAs themselves, the Risk-Based Inspection Guides for those plants, and calculations with PC-based PRA models. Manual valves identified as important in multiple plants were included in the generic lists of important manual valves (Table 5).

Collection of Upgrade Information

Plant personnel coordinating the site visits arranged for the assessment team to speak with individuals familiar with human-engineering upgrades (in progress, recently completed, or planned) at LCSs. The team sought information from these personnel (typically human factors specialists and labeling coordinators) about relabeling programs, upgrades to normal or emergency lighting, improvements to communication systems, noise surveys or noise abatement efforts, and efforts to improve accessibility of components (e.g., installation of platforms). Costs associated with upgrades were noted where available.

Human Factors Evaluation of Local Control Stations

LCSs and their surroundings were observed from a human engineering perspective, including labeling, control and indication, lighting (including emergency lighting), and accessibility. Multifunction LCSs were also evaluated on the attributes identified by O'Hara et al. (1990) - functional centralization and panel design. The checklist used to record this information is shown in Appendix C. At each LCS, operators/guides talked through the appropriate portions of the procedures, and the assessment team noted on checklists or in the procedures such items as agreement of terminology in procedures with in-plant labels, requirements for and availability of feedback indication, and the need for and availability of communications devices. If requested by plant personnel at the end of the site visit, the assessment team provided a summary description of important observations that they had made.

Table 4. PRAs Used to Identify Important Manual Valves

Boiling Water Reactors	**Pressurized Water Reactors**
Brunswick	Arkansas Nuclear One Unit 1
Grand Gulf	Indian Point Unit 3
Limerick	Oconee Unit 3
Millstone Unit 1	Seabrook
Shoreham	Zion

Table 5. Generic Lists of Important Manual Valves for PWRs and BWRs

Pressurized Water Reactor
• **Pump Suction and Discharge Valves in:** - High Pressure Injection (HPI) and Safety Injection (SI) - Low Power Injection (LPI), Residual Heat Removal (RHR) - Service Water (SW) - Auxiliary Feedwater (AFW), Emergency Feedwater (EFW) • **Cooling Water Isolation Valves to key components:** - SW and Component Cooling Water (CCW) valves to CCW heat exchangers - HPI/SI pump heat exchangers - LPI/RHR pump heat exchangers - Emergency Diesel Generator (EDG) heat exchangers • **Test Line Valves to:** - Borated Water Storage Tank (BWST) - Refueling Water Storage Tank (RWST) • **Key System Cross-Connect Valves**
Boiling Water Reactor
• **Standby Liquid Control Valves** - Common injection line valve - Poison tank outlet valve - Test tank suction and return valves • **Manual Injection Line Valves** - Low Pressure Coolant Injection (LPCI) - Core Spray (CS) • **Service Water (SW)** - SW pump cooler valves - SW pump discharge valves - High Pressure Core Spray (HPCS) cooling inlet & outlet valves - EDG cooling inlet & outlet valves • **Room Cooler Valves for:** - High Pressure Coolant Injection (HPCI) - Reactor Core Isolation Cooling (RCIC) - Residual Heat Removal (RHR) - Core Spray (CS)

Summary of Evaluations

After each site visit, both members of the team independently generated summary ratings of the LCSs on the categories of human engineering identified during the review of relevant documents: labeling, indication, control, environment, and communications. For each category, the overall conditions at a plant were designated either low (i.e., deficiencies present), medium (i.e., less than optimal), or high (i.e., favorable elements present). The human engineering design of major multifunction panels (e.g., remote shutdown panels) and of important manual valves was separately rated. Appendix C contains the Summary Evaluation Form used.

2.3.2 General Findings

Human Engineering Upgrades at LCSs

All of the plants visited cited current or recently completed human engineering upgrades to LCSs. The most common effort was relabeling. However, the scope and quality of the relabeling programs varied widely both plant to plant, and within plants. A few plants were making a concerted effort to place a new, clearly legible, consistently formatted, color-coded tags on all significant components. In other cases, the relabeling program might better be described as selective label replacement.

Although many efforts to upgrade LCSs are undertaken in response to regulatory activity (e.g., emergency operating procedure inspections), the majority seem to be initiated from within the plant, typically based on input from operators or in response to operating problems. Some examples of such upgrades are given in the discussion of good practices, below.

Operator Comments on Upgrades

Operator opinion was elicited on improvements to human engineering made to LCSs in their plants, and when possible, equipment operators out in the plant were questioned as to the effectiveness of the upgrades. They also were asked to identify the most beneficial upgrades.

In general, operator response was positive. This was expected because LCS improvements were often initiated at the suggestion of operating personnel. Examples include platforms to facilitate access to valves, sound-attenuating enclosures at pager stations in areas of high noise, and pre-staged, color-coded sets of jumper wires. However, there were instances in which human engineering improvements missed the mark, according to the operators. In one plant, for example, operators did not view new labels as an improvement, possibly because although the new color-coded, engraved metal labels carried more information (e.g., component name) than the older stamped metal tags, neither was very easy to read; further, the operators interviewed were not familiar with the new color-coding scheme. In another plant, large stamped metal "license plates" carrying the component numbers of overhead valves were being replaced by more informative labels (i.e., tags containing the name of the component in addition to its number and a bar code identifier). Unfortunately, the new labels were too small to be read at typical viewing distances.

Good Practices

Noteworthy and varied examples of good human factors practices at LCSs were observed in all of the plants visited. Some reflected the plant-wide application of current, generally accepted human

engineering good practices (e.g., recommendations contained in EPRI documents regarding labeling, and sections of NUREG-0700 relevant to the design of gauges and meters or multifunction panels), while others were aimed at improving a particular type of operator interface. For example, as suggested in the preceding paragraph, labeling of overhead valves can pose problems. In one plant, new labels were placed on chain-operated valves by attaching the label to a short length of plastic pipe, through which the chain passed freely; thus the label was always at the bottom of the loop of chain and did not interfere with operation of the valve. This practice is illustrated in Seminara (1988). To help operators locate overhead valves that were not chain-operated, some plants painted identifying information on the floor directly below the valve. Others hung readily visible placards directing attention to the location of the out-of-the-way equipment.

Some good practices were aimed at avoiding specific errors. Electrical cabinets in one of the plants visited had a hole near the bottom corner of the front panel into which a tool was inserted to operate the breaker. Each cabinet had an identifying label at eye height in the center of the front panel. There was also a second, smaller label carrying the same information near the hole in the bottom corner, where it could not be easily read by a standing operator. When asked the reason for the duplicate label, the plant guide explained that an operator, after reading the first label and positioning himself in front of the correct cabinet, might, upon bending down, inadvertently place the tool in the hole in the adjacent panel (since the holes are at the edges of the cabinets, not in the center). The second label, just above the hole, is positioned to allow a final check before the breaker is operated, thus greatly reducing the likelihood that the wrong breaker would be operated.

At least two of the plants visited prepared sets of jumper wires to aid operators in performing procedures that called for temporary connections or bypasses to be made in electrical panels out in the plant. These were labeled with the procedure number and stored where they could readily be accessed by operators. The wires were fitted with the appropriate connectors (e.g., with spring-loaded insulated tips, banana plugs), were labeled with their intended connection points, and were cut to the correct length. In addition, the colors of the wires corresponded to the color codes of the points in the panel that were to be connected, thus allowing operators to complete the required action quickly with a minimal likelihood of error.

The practice with perhaps the greatest potential to improve human factors out-in-the-plant was a program to enlist the aid of operating personnel in evaluating the adequacy of LCSs. Operators walking down procedures were provided with "Local Action Checklists" on which they could record, for each procedure step, the accessibility of the component, the adequacy of the lighting, possible radiological hazards, the staffing required to perform the action, and any other information bearing on the ability of operators to perform the local action. Upgrades then were designed based on the results of the checklists.

Practices to be Avoided

The human engineering weaknesses were as varied as were the strengths; undesirable practices could be identified even in plants that having good human engineering overall. It was commonly observed that, except for the (re)design of remote shutdown panels, plant (or utility) human factors specialists were almost never involved in human engineering activities outside the control room. This is not to say that it would be desirable for all upgrades to originate with human factors personnel; effective upgrade efforts usually grow out of information from the operating staff. However, the lack of human factors participation can lead to unforeseen problems or less than optimal results. For example,

the arbitrarily assigned colors used to code trains on one plant's otherwise exemplary labeling program were not the same colors used to code trains in the control room.

The replacement of brass tags stamped with a component identification number with engraved labels which were no more legible than the original tags was mentioned in the discussion of operator comments on upgrades. These "improved labels" were aluminum with an anodized surface, the color of which coded information about the component or system; the engraving revealed the underlying metal. Unfortunately, contrary to available labeling guidance, a serif* typeface with a narrow stroke width was used. A bold, sans-serif typeface is typically recommended for optimal legibility (see e.g., Seminara, 1988). Furthermore, the legibility of the labels varied depending on the surface color. The code employed silver as one of the colors, resulting in labels with virtually no contrast between the lettering and the background. Guidance is available regarding preferred, high contrast color combinations for lettering and backgrounds (see, e.g., NUREG-0700). Black lettering on a white background provides maximum contrast; color coding may be added by using a colored border on the label.

It was not uncommon to find extraneous information on displays and components. (According to NUREG-0700, display of unnecessary information should be avoided since it may interfere with efficient performance; Seminara (1988) also cautions against superfluous information.) For example, calibration stickers were often placed on the faces of gauges and meters. While none were observed that obscured the scale or pointer (Hartley, et al. noted such cases), the stickers often covered the units legend (e.g., volts, direct current; pounds per square inch) for the indicator. In one of the newer plants, adhesive labels indicating that components had been "turned over" from the construction organization were affixed to many of the electrical switches. This resulted in considerable visual clutter and, in the case of arrays of smaller switches (as in a distribution panel) prevented clear labeling of the switches. Another source of extraneous information was old labels, which in many cases had been left in place after equipment was re-labeled. While the presence of two or perhaps three generations of labels on a component allowed the assessment team to make instructive before and after comparisons, the continued presence of old, presumably inadequate, labels could cause delay or confusion. Seminara (1988) suggested that the presence of informal, improvised labels points to a need for formal labels; he recommends that makeshift labeling be removed once formal labels are in place.

Most plants, even those with obvious problems, were quite satisfied with their upgrades and their LCSs in general. That is, in many cases, individuals responsible for the LCS upgrades seemed to be unfamiliar with generally accepted standards in human engineering design, and unaware of the good practices that other plants have instituted. This is not surprising, given the earlier noted lack of human factors participation in LCS upgrades. As an example, some plants failed to avoid poor practices that had been specifically identified in NRC documents (e.g., Persinko and Ramey-Smith, 1986). In other cases it was clear that plants had not made use of guidance developed by industry (e.g., Seminara, 1988).

*A serif typeface includes characters with short lines extending from and at an angle to the upper and lower ends of the strokes of each letter (this typeface is an example).

2.3.3 Specific Issues

Indication of Valve Position

During the site visits, an attempt was made to examine the appropriate (BWR or PWR) important manual valves (IMVs) which had been previously identified on a generic list (Table 5). In each plant, it was usually possible to observe most of the IMVs, but in some cases, the systems or valves did not exist at the plant, or the valves were inaccessible (e.g., due to high radiation). Table 6 gives the results of the team's observations from a PWR and a BWR plant.

The human engineering aspects of IMVs viewed during the site visits varied in quality. At most plants, some IMVs were not easily accessible. Typically, the overall design and condition of the IMVs was similar to that of other manual valves in the plant; that is, with only a few exceptions, the plants gave no special attention to non-EOP valves classified as important from a PRA standpoint.

IMVs generally lacked any local indication of position. Without such explicit indication the position of a valve must be inferred from stem position (for rising stem valves) or determined by checking the position of the valve manually in the closed direction. Both methods have potential problems. Inferring the valve position from the appearance of the stem is uncertain, at best. Operators cannot be certain if the stem is rising or not without operating the valve, and even if it is rising, the actual positions of the stem for full closed and full open are not marked and may not be known. Checking the position of a valve by attempting to close it (the standard method) can be misleading if the valve is stuck on the open seat. One operator related a story of checking a chlorine system valve in this manner. Because the valve was actually stuck open, he was exposed to chlorine exhausted from the valve and had to be hospitalized briefly.

In some cases, valves with dial-like position indicators were installed so that the indication was facing the floor so that it could not be easily seen. Local position indication, when present, was also generally not maintained very well. The indicators were frequently incorrect and apparently were not regularly calibrated. Often, valves were known by the operators to be full open (or full closed), but the indicator was in some intermediate position. In other cases, a position beyond full open or full closed was indicated. In these cases, a full open or closed reading could be obtained with the valve actually in an intermediate position. Position indicators were observed to be painted over on some valves. On others "open" and "closed" markings were missing entirely. Informal indications (consisting of tape or magic marker) had been added to some of these valves; this practice is undesirable because such markings may be ambiguous, inaccurate, and subject to wear or removal. Because of conditions such as these, many operators dismissed the local indication, stating that they would not trust it.

Table 6. Sample Observations for Important Manual Valves

Pressurized Water Reactor
• **Emergency Cooling Water (ECW) to Diesel Generator coolers (inlet and outlet valves)** - Valve tags have both embossed metal and engraved metal types; difficult to read - Not color-coded - Position indication provided but out of calibration
• **CCW Heat Exchanger valves** - ECW in: embossed metal tag; position indication - ECW out: embossed metal tag; position indication, throttle valve - CCW out: valve with old embossed metal tag; position indicator, but no marking - CCW in: not observed
• **CCW Pump - Discharge Valve** - Very old worn tags - Position indication
• **CCW Pump - Suction Valve** - Very old worn tags, very inaccessible - Position indication
• **Some PWR generic IMVs could not be viewed:** - HPI and LPI and ECW pumps have only MOVs. - HPI, LPI pumps had no SW/ECW cooling. - RHR pumps inside containment - not observed. - Cross-connects: operators stated they essentially use no cross-connects.
Boiling Water Reactor
• **HPCS - Diesel Generator Cooling Water Inlet and Outlet Valves** - All stamped metal tags, no position indication.
• **EDG - Cooling Water Inlet Valves** - Stamped metal tags (colored), in poor condition.
• **EDG - Cooling Water Outlet Valves** - Stamped metal tags (colored), in poor condition. - Throttled, set by flow gage and procedure, no other position indication.
• **SLC Test Tank Inlet and Outlet Valves** - Tank outlet control room position indication via limit switches - Tank inlet/return: stamped metal tag, no position indication, non-rising stem
• Most of other BWR IMVs for the plant were in high radiation or contaminated areas.

Emergency Lighting

Before the site visits, the assessment team reviewed the NRC requirements for emergency lighting. Appendix R, Section III.J of 10 CFR 50 calls for emergency lighting units, with at least an 8-hour battery power supply, in all areas needed for operation of safe shutdown equipment as well as in entry and exit routes. Some additional guidance is provided by Section 9.5.1 of the NRC Standard Review Plan (SRP), which deals with lighting and communication. Self-contained fluorescent or sealed-beam units are required in areas and routes manned for safe shutdown, including those manned for evacuating the control room. Battery-powered portable hand lights also are required for emergency use by the fire brigade and operations personnel. Section 9.5.3 of the NRC SRP, "Lighting Systems," specifies that the emergency lighting system should provide adequate lighting during all plant operating conditions, including fire, transients, accident conditions, and loss of offsite power. It also cites the Illuminating Engineering Society Lighting Handbook for system design and illumination levels. NRC Generic Letter 86-10 states that the level of illumination should be sufficient to enable an operator to reach the needed areas and to perform the necessary functions. It also states that the licensees should verify by field testing that the lighting is adequate to perform the intended tasks. The NRC Inspection and Enforcement Manual has a section on emergency lighting that describes the inspection steps to be used to verify the adequacy of the plant's emergency lighting to satisfy Appendix R.

NRC requirements for mitigating a SBO event are contained in 10 CFR 50.63, "Loss of All Alternating Current Power." Regulatory Guide 1.155, "Station Blackout," gives further NRC guidance for this event. Steps 3.2.4 and 3.2.6 of this document apply, in general, to lighting concerns for the blackout event. Step 3.2.4 specifies the evaluation of equipment needed to maintain lighting and habitability for those areas that operators are required to enter during the blackout and recovery period. Step 3.2.6 states that consideration should be given to operator actions both inside and outside the control room. This is considerably less prescriptive and less detailed than the guidance on lighting necessary to satisfy 10 CFR 50 Appendix R, for fire response and control room evacuation. Also, in contrast to the requirements related to Appendix R, there is currently no NRC inspection manual guidance or required inspection to cover SBO. Thus, there are more specific requirements and guidance for emergency lighting related to evacuating the control room than for SBO.

The procedures selected for use in the walkdowns of LCSs provided an opportunity to observe operating stations that were covered by the requirements and guidance associated with control room evacuation and SBO. It was noted that the execution of these two procedures took the operators to different sets of LCSs. During the walkdowns, the availability and placement of battery-powered emergency lights were noted, but illumination levels were not measured. Emergency lights were always found at stations used in the control room evacuation procedures (as required by Appendix R). However, there were instances in which LCSs used for the SBO Procedure did not have permanent emergency lights; operators stated that flashlights would be used in those cases. Plants should evaluate the availability of flashlights for SBO and the ability of operators to perform necessary tasks while manipulating flashlights.

2.4 Summary

Conclusions based on the results summarized in Sections 2.2 and 2.3 are presented below, in Sections 2.4.1 and 2.4.2 respectively.

2.4.1 Review of Literature and Operating Experience

General literature and reports of operating experience were reviewed to determine the extent and type of human engineering deficiencies at component-level LCSs in nuclear power plants; events involving five types of human engineering deficiencies were tabulated, representing a sampling of the types of human engineering deficiencies and their significance.

The review suggests that human engineering deficiencies at both multifunction and single-function LCSs are quite common across the industry. Additionally, these human engineering deficiencies are significant in that they often occur at equipment specified for operation in EOPs, they have caused or contributed to reportable operational events, and they continue to be noted as needing corrective actions in reports from industry and the NRC.

Several problems involving local indication of valve position were identified in Licensee Event Reports (LERs), NUREG/CRs, and EOP inspections. Instances in which inadequate indication of valve position was clearly identified as the cause of the problem appear in Appendix A of this report under "Indication Deficiencies." In many more cases, there were problems related to valves which may have been caused by poor position indication, but there was insufficient documentation to determine the root cause.

2.4.2 In-Plant Assessment

The design of multifunction and single-function LCSs is highly variable both within and between plants. Marked differences existed between plants - including plants operated by the same utility. Human engineering was not always better in new plants than in older plants, which seemed, in some cases, to have benefitted from upgrades undertaken based on operating experience. Within plants, it was not unusual to find examples of both good and poor practices. Variability also was found within the dimensions on which LCSs were evaluated. For example, labeling of switchgear might have been very good, while valves were poorly labeled. Some variation can be attributed to the lack of a systematic design approach and the failure to use specific HFE guidelines for LCSs.

In summary, many instances of good or even exemplary human factors practice were observed, but there were also many opportunities for improvement. This is an important fact, since many instances of plant-level problems or events caused by inadequate human factors at LCSs were noted in reviewing operating experience.

3.0 CONCLUSIONS

The overall results of this research demonstrate that human engineering deficiencies at LCSs can negatively affect plant operation. The review of operating experience indicates that such deficiencies still exist, and demonstrates that they can lead to operator errors having potentially significant consequences. This conclusion was reinforced by in-plant assessments of LCSs.

In addition to confirming the existence of significant human engineering deficiencies at LCSs, the in-plant assessments gathered information about the human engineering upgrades made at nuclear power plants. Upgrades are typically the result of any of three influences - regulatory activity, industry initiatives, and in-plant programs. NRC inspections of remote shutdown panels and related control stations (i.e., Appendix R reviews and walkdowns associated with EOP inspections) have lessened the plant-to-plant variability in the quality of human engineering design of these stations. Remote shutdown panels tend to be adequately designed and well provided with normal and emergency lighting. Similarly, equipment referenced by EOPs is often identified with special high-visibility labeling and is typically well lit. In addition to upgrades made in response to or in anticipation of NRC inspections, plant personnel also cited the improvements made as a result of activities of industry groups. Labeling upgrades were frequently cited in this regard; plants consulted the guidance developed by INPO and EPRI. Finally, many upgrades of the LCS environment principally affecting equipment operated regularly, were made at the suggestion of operating personnel.

While these factors have mitigated human engineering deficiencies at many operator interfaces, still other interfaces are deficient. The condition of important manual valves is an example; valves that were not related to remote shutdown or other emergency operating procedures and were infrequently used typically had not been upgraded. Consequently, although mispositioning of these valves can have potentially serious consequences, some important valves lacked position indication, were difficult to access, and/or were poorly labeled.

Thus, the overall results of efforts to improve human engineering outside the control room have been uneven, and the variability in the quality of human engineering at LCS noted by Hartley, et al. (1984) and O'Hara, et al. (1990) still exists. This variability may be due to the fact that upgrades typically are not part of a comprehensive human engineering program, nor are licensee human factors personnel typically involved in designing operator interfaces outside the control room. Plant personnel often seemed to be unaware of how control stations in the plant compare to typical industry practices or accepted human engineering principles. The issue of variability is significant for several reasons. Variation within plants results in the lack of a consistent operator interface and, therefore, can increase demands on the operator, cause potential confusion during periods of high workload, and increase the probability of operator error. Variation between plants makes it difficult to identify solutions to LCS issues that are applicable to the entire industry.

3.1 Implications for Current Practice

The quality of LCSs might be improved if there were greater awareness of existing human engineering guidance on these operator interfaces, available from a variety of sources. Many sections of NUREG-0700 can be applied to LCSs, especially multifunction panels. However, NUREG-0700 was not intended to apply to the variety of operator interfaces and range of environments encountered outside the control room; other sources of guidance are required for such circumstances. General human engineering references can be consulted (e.g., MIL-STD-1472D; VanCott and Kinkade, 1972) which,

although not specifically oriented toward nuclear power plant applications, are broader in scope than NUREG-0700. There is also relevant guidance that is specifically tailored to nuclear power plant applications (e.g., the detailed plant labeling guidelines in Seminara, 1988). Further, much of the human engineering guidance assembled by EPRI in the context of maintainability can be applied to LCSs (e.g., Seminara, 1982; Pack, et al., 1985). To make such guidance more readily accessible, guidelines from the sources cited above were compiled and are given as Appendix D. The appendix is organized according to the dimensions identified for single-function LCSs, providing guidance on labeling, indication, control, environment, and communications.

Practical limitations (e.g., cost and scheduling) have often required that improvements in human engineering outside the control room be performed gradually. These efforts, although incremental, should not be ad hoc. Any modification, whether explicitly for improving human engineering or not, should adhere to current, accepted human engineering standards. Further, proposed designs should take into account operators' requirements and limitations. Existing plant practices (e.g., labeling and coding) should also be considered. Satisfying all these conditions will require tradeoffs to be recognized and resolved. Therefore, the design of operator interfaces outside the control room should be coordinated by personnel familiar with operational and human engineering issues.

Efforts to upgrade LCSs typically concentrate on operator interfaces that are subject to inspection (e.g., in connection with EOP inspections) and components that are frequently operated. The results of the value/impact analysis for upgrades of important manual valves indicate that plants should also consider the risk-significance of actions performed at LCSs in setting priorities for upgrade efforts. While many EOP-related components are risk-significant, there are components at which important actions are taken that are not referenced in EOPs. Consequently, by "targeting" components involved in risk-significant actions for human engineering upgrades, a plant can achieve the greatest risk reduction value for the resources expended.

3.2 Implications for Future Plants

The results of previous research (O'Hara, et al., 1990) demonstrated the importance of considering human engineering during the design process. In that study, it was shown that centralization of functions at multifunction control panels was associated with large potential reductions in risk. However, the cost of backfitting this attribute was estimated to be quite high, and the value/impact of the upgrade was therefore reduced. The same point is illustrated in this study for indication of the position of manual valves. Valve manufacturers reported that the cost of providing a position indicator on a new valve was relatively small, whereas the costs of backfitting such indication on in-place valves would vary considerably and could be prohibitive. Thus, while adding position indication in an existing plant might only be feasible for a selected set of valves, it could be specified for many (or all) valves in the design of a new plant for relatively low cost. It should be noted that the nature of the position indication should be appropriate to the use of the valve.

Like the workstations in the control room, LCSs are interfaces between the operators and the plant, and the approach to their design should reflect the same human engineering considerations given to the main control room, i.e., they should be designed using the same human factors engineering methods, standards, guidelines, and principles. The design of LCSs should be guided by the function and task analyses used to analyze the human role in the plant. It should be determined that functions to be performed at LCSs will not be compromised by human limitations and that the design of the LCS meets the needs of the operator for process information, means of effecting control, feedback regarding

the results of control actions, and an adequate working environment. In addition, the design of a LCS should be consistent with that of other local control stations and with the control room and should conform to *plant-wide* conventions regarding coding, labeling, information display, and operation of controls.

In discussing problems that might be anticipated with future LCSs, Hartley et al. (1984) point to the allocation of an increasing number of local control functions to automatic or semiautomatic systems (as opposed to human operators). The difficulties they anticipated were the same as those that can arise from increasing automation in the control room, i.e., the potential loss of operators' situation awareness, and hands-on control skills (O'Hara and Hall, 1990) as their primary role becomes one of monitoring rather than controlling. A related observation was made during the plant visits undertaken for the present study. At all of the plants, operators in the control room had access to computer-based displays in addition to conventional instrumentation. These displays provided high-level information, e.g., indications that represented an integration of several parameters, or the value of a set of parameters plotted over time. However, in only one of the plants were such displays available at the remote shutdown panel. Similarly, the design for the Advanced Boiling Water Reactor (ABWR) calls for a conventional remote shutdown panel. Thus, operators at remote shutdown stations might be forced to gather information about the status of the plant and the effectiveness of their actions by unaccustomed means. The designs of new or upgraded remote shutdown stations (and the content of related procedures and training programs) should ensure that the operator interface provides a level of support for operator actions comparable to that available in the control room.

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Van Cott, H.P., and Kinkade, R.G. (eds.), "Human Engineering Guide to Equipment Design," American Institute for Research, Washington, D.C., 1972.

APPENDIX A
EXAMPLES OF HUMAN ENGINEERING DEFICIENCIES at LOCAL CONTROL STATIONS

Table A-1. Human Factors Deficiencies at Local Control Stations - Labeling Deficiencies

Facility & Source	Description
Beaver Valley EOP 90-80	"In-plant labelling of valves had been performed using stainless steel strips with embossed letters and numbers. This method of labeling provided no contrast between the valve identification letters and numbers and the label background making it nearly impossible to readily identify the valve from a distance of 6 feet or greater."
Kewaunee EOP 89-12	"Labeling of chain-operated overhead valves on the valve body (instead of the chain) was often difficult to read and would be especially difficult in degraded lighting conditions."
Waterford 3 EOP 88-18	"The labeling of some components...required in the EOPs were deficient. Some of the inaccessible valves were inadequately labeled with metal, dog-tag type labels. These cannot be read from a distance. They were small and can easily become dirty, eroded or broken off."
Cooper LER 88-017	"...two unplanned actuations of engineered safety features (ESFs) occurred while performing a recently revised surveillance test to verify the integrity of all circuits which initiate starting of the diesel generators (DGs). The first ESF actuation involved an unplanned start of DG #1 when the starting circuit for DG #2 was being checked. The cause was due to jumper installation in the 1AN breaker cubicle in lieu of the 1BN breaker cubicle. The second ESF actuation involved an unplanned start of core spray (CS) Pump B. The cause was due to selecting the wrong relay (one mounted below the nameplate identifier as opposed to the one above) for installation of relay contact blocks."
Millstone EOP 88-10	"Several labels in LCSs were difficult to read due to small or handwritten labels. In addition, some labels lacked needed information. For example, the "emergency button" in the diesel room has no label indicating whether the button starts or stops the diesel."
St. Lucie EOP 88-08	"Labels for components throughout the plant were difficult to read due to engraved labels and small letter and number size. The engraving has the potential to become filled with dirt or erode. Additionally, some labels were positioned on an adjacent component, posing a potential for operator error."
Ft. Calhoun LER 87-036	"...the operator inadvertently positioned the incorrect switch in override, subsequently enabling the test signal to initiate the auxiliary feedwater actuation signal. Both auxiliary feedwater pumps started, but no auxiliary feedwater was injected to the steam generators...investigations of the event revealed that the similarity in labeling between switches was the overriding factor of operator error."

Table A-1. Human Factors Deficiencies at Local Control Stations - Labeling Deficiencies (continued)

Facility & Source	Description
Vogtle LER 87-064	"...an auto-start signal was initiated for the motor-driven auxiliary feedwater (MDAFW) pumps when an operator, performing a clearance of a standby condensate pump (CP), inadvertently operated the wrong handswitch of the local condensate valve control panel. The discharge valve for the operating CP closed which caused a trip of a main feedwater (MFW) pump on low suction pressure (the other MFW pump was in the tripped position). The MFW pump trip resulted in (1) a start signal to the MDAFW pumps which were already running, and (2) the AFW discharge flow control valves stroked full open. Control room operators responded quickly to throttle the AFW discharge control valves and were able to maintain steam generator water levels within the desired range. The labels on the local condensate control panel contributed to this event's cause. The labels will be modified for this local panel and a review will be performed of other remote panel to identify if similar labeling modifications are needed."
Byron LER 87-019	"The EO opened the system aux transformer disconnects instead of the main power transformer disconnects. The safety related 4kV buses were deenergized causing the emergency diesel generators to start, reenergize the buses, and sequence the safe shutdown loads...permanent, descriptive labels have been placed on MPT and SAT switchyard disconnects."
Cooper LER 87-009	"...a reactor scram occurred accompanied by Group II, III, and VI isolations when the operating reactor feed pump was mistakenly tripped by a station operator from the LCS. The station operator (unlicensed operator) had been dispatched to conduct a local trip test of the standby reactor feed pump turbine which was in the initial stages of being placed in service. Upon entering the feed pump room, he apparently became disoriented with respect to north-south direction and pump location and tripped the operating pump...a contributing cause is considered to be the lack of human factors in component/equipment markings."
Susquehanna AEOD/T706 LER 86-038	A radiation monitor trip caused actuations of Control Room Outside Air Supply system and Standby Gas Treatment system. An I&C technician performed a test procedure on the wrong component due to incomplete component labeling.
Pilgrim AEOD/T706 LER 86-025	The fire water supply system was inoperable and the electric motor driven fire pumps suffered mechanical damage due to an inadvertent alignment of the fire pump suction valves to a drained storage tank. The valves were incorrectly labeled due to errors in the P&ID.
Sequoyah AEOD/T706 LER 86-029	Standby diesel generators started on loss of voltage to the IB-B 6.9kV shutdown board. An assistant shift engineer went to the wrong board and tripped the normal feeder breaker to the IB-B 6.9kV shutdown board instead of the alternate feeder breaker to the IB-B shutdown board. Signs were added to the ends of each board and each panel of the 6.9kV unit boards were labeled with the board designation.
Brunswick AEOD/T706 LER 86-024	Core spray subsystem pumps inadvertently auto-started, injecting 7500 - 9000 gallons of water into the reactor during a cold shutdown. Maintenance technicians broke the contact of the power lead to Unit 2 power supply inverter when they should have been working on the Unit 1 inverter. Changes were made to the identification tags of the inverters.

Table A-1. Human Factors Deficiencies at Local Control Stations - Labeling Deficiencies (continued)

Facility & Source	Description
Beaver Valley AEOD/T706 LER 86-012	Reactor trip caused by inadvertent actuation of wrong train reactor trip shunt breaker during a test. Partially attributed to labeling problems.
Sequoyah AEOD/T706 LER 86-038	While performing a trip check on the 6.9kV unit board 2D differential relays, the 2C board and its associated shutdown boards were inadvertently deenergized. The 2C board relays are located next to the normal feeder breaker for the 2D board, causing the misidentification. Corrective action was to paint stripes between the boards.
LaSalle NUREG-1192 LER 85-012	A RHR shutdown cooling isolation occurred due to an instrument maintenance technician working on the wrong valve. Although labels existed, they were never used because they were not trusted.
McGuire NUREG-1192 LER 85-010	Incorrect valve in upper head injection piping was operated due to an incorrect temporary (magic marker) label.
N. Anna NUREG-1192 LER 85-006	There was a deenergization of the 120V AC vital bus when a non-licensed operator deenergized the breakers on the wrong train. The labeling was non-unique and the load list was missing on the cabinet.
Kewaunee IE IN 84-58 Ref. 10 LER 84-001	Both trains of shield building ventilation were taken out of service for one hour when maintenance personnel began work on the wrong train during a surveillance procedure. Labeling deficiencies were part of the cause.
Fitzpatrick IE IN 84-58	RCIC was disabled with HPCI unavailable when maintenance technicians calibrated the RCIC turbine speed instrumentation instead of the corresponding HPCI instrumentation. This disables the entire high pressure injection function for the plant. Subsequently, the identification of the HPCI and RCIC equipment was improved.
LaSalle NUREG-1192 LER 84-017	A loss of feedwater occurred partially due to the poor readability of labeling and failure to use a "caution" label.
McGuire NUREG-1192 LER 84-021	High flux rate signal was initiated by an instrument technician working on the wrong train due to poor label placement.
Surry NUREG-1192 Ref. 10	The torque switch for an operable MOV was removed rendering the MOV inoperable. The switch from a valve in another unit was supposed to have been removed. The error was partially attributed to poor readability of the labels.
McGuire NUREG-1192 AEOD/S401 LER 81-180	Containment temperature exceeded Technical Specifications when non-licensed operator closed the containment ventilation isolation valve on the wrong unit. The valve was mislabeled following station modifications.

Table A-1. Human Factors Deficiencies at Local Control Stations - Labeling Deficiencies (continued)

Facility & Source	Description
Hatch NUREG-1192 LER 82-118	A plant employee escorted factory representatives to the wrong unit diesel generator room for maintenance activities and the diesel was tripped. The diesel generator room doors have since been labeled with the appropriate diesel generator numbers.
Hatch NUREG-1192 LER 82-095	Both loops of the RHRSW system were made inoperable when the "A" loop strainer inlet valve was inadvertently closed instead of the "B" loop valve during "B" loop maintenance. New I.D. tags and separate keys for each valve were the corrective action taken.
Calvert Cliffs NUREG-1192 LER 82-018	Two control element assemblies (CEAs) dropped into the core resulting in a pressurizer level deviation of greater than 5%. Electricians inadvertently disconnected power from the CEAs when they started working on the Unit 2 CEAs instead of those of Unit 1. The equipment is in different rooms but is not clearly identified.
Salem NUREG-1192 LER 82-003	Two diesels were locked out (inoperable) at the same time when a non-licensed operator misinterpreted the tags on the Diesel Lockout Switch. The "ON" position means the diesel is locked out. The tags were changed from ON and OFF to LOCKOUT and DIESEL IN SERVICE, respectively.
Surry NUREG-1192 LER 82-001	One of the two boric acid flow paths to the core became inoperable when a valve in the wrong unit was closed. The valve labeling was illegible because it was too small and was crusted with boric acid residue.
Big Rock Pt. NUREG-1192 LER 81-022	Two of four blowdown loops of the reactor depressurizing system were made inoperable (three of four required) when an auxiliary operator opened two breakers in the wrong loop during maintenance. All the breakers and controls on the four power panels in separate rooms had identical markings.
D.C. Cook NUREG-1192 LER 81-005	Five motor-operated valves on the Safety Injection Train were deenergized on the wrong unit. The components at a valve control center were not identified by labels.
Peach Bottom NUREG-1192 LER 81-008	Primary containment integrity was breached to secondary containment when a wrong train isolation valve was closed prior to cutting the piping during installation of a new penetration test connection to a containment atmospheric dilution line. The isolation valves lacked clear I.D. tags.

Table A-2. Human Factors Deficiencies at Local Control Stations - Indication Deficiencies

Facility & Source	Description
Vogtle LER 89-031	"The root cause for the event was cognitive personnel error involving reassembly of the HDT high-level dump valve. The valve was reassembled such that its position indication showed closed when it was actually fully open."
Sequoyah LER 89-007	"An investigation revealed that the transfer switch associated with Unit 2 RCP No. 4 on 6.9kV unit board 2D was misaligned. This incorrect position aligned the 2 breakers to the same DC power supply. The cause of the event was attributed to the mislabeling of the transfer switch's position."
Limerick LER 89-027	"Incorrect reactor vessel (RV) boundary valve position during performance of a Local Leak Rate Test (LLRT) caused the draining of 400 gallons of RV inventory...during re-verification of valve alignments, the LLRT crew discovered the mispositioned valve, due in part to the handwheel being reversed such that it indicated closed when, in fact, the valve was open."
Waterford EOP 88-18	"Operators are directed to locally verify that the Seal Oil System is operating. During a walkdown, however, no local indications were found." p.23 "Operators must verify that the MFW Pump Turbine Gland Seal Steam Pressure Controller 'maintains 4 psig.' The controller is not clearly labeled. The unit is labeled 'psi.' It is not possible to visually perceive exactly 4 on the scale." p.23
San Onofre EOP 88-13 EOP 88-14	"Another source of difficulty is the manipulation of the Inverter via the Manual Transfer Switch...The switch is located about seven feet above the floor on a panel, is very large and because it is so high obstructs the position labels, i.e., 'Inv.' and 'Line.' A red light that indicated which position the switch is in is too dim to be readily detected. The switch is also very heavy, requiring two hands and a substantial effort to manipulate it." p.34
Wolf Creek EOP 88-13	"The valve position of [solenoid valves] can not be field verified. The procedures should be changed to have an operator close the manual valves if doubt exists as to whether a solenoid valve is open or closed." p.7 "A work request will be written to paint outside purge valve position indicators with a glow-type paint as the portable light an operator would wear would not reach high enough to illuminate to position indicators." p.12
Crystal River EOP 88-09	"The 'B' 'RELAYS ENERGIZED' light on the RSP is covered with a green lens cap, while the "A" light has no lens cap. Since plant color conventions call for a red indicator to indicate energization, this discrepancy should be corrected."
Surry LER 87-008	"One of the three control/relay room chillers tripped...this occurred when an operator was attempting to decrease chiller condenser pressure by opening the condenser SW discharge valve. This is a quick throw ball type valve installed in a vertical run of pipe. The valve handle is removable and is used on corresponding valves for the 'B' and 'C' chiller units. Because he was standing behind the valve, the operator could not see that the valve handle had been installed 90 degrees out of position. Consequently, as he aligned the valve handle to the flow direction, the valve actually closed."

Table A-3. Human Factors Deficiencies at Local Control Stations - Control Deficiencies

Facility & Source	Description
Fermi 2 LER 89-029	"A half scram signal was received when power was lost on reactor protection system bus "B." Several engineered safety features were actuated. The loss of RPS bus "B" was attributed to the location of a breaker operating switch in a high traffic area in the plant. A security investigation was conducted to determine if any personnel could have bumped the switch."
Salem 1 LER 89-030	"1C D/G was tripped when its emergency trip push button was inadvertently pushed. A worker had gone between erected scaffolding and the D/G control panel and in so doing, brushed up against the push button, actuating the D/G trip. The D/G emergency push button extends approximately 3 inches out from the control panel."
Cooper LER 89-004	"...a #1 emergency diesel generator (EDG) trouble alarm was received due to an inadvertent actuation of the safety shutdown valve overspeed trip lever. The condition would have prevented the EDG, which was in standby, from starting in either automatic or manual. At the time of the occurrence, the redundant #2 EDG was out-of-service for maintenance. The inadvertent actuation of the overspeed trip was caused by utility personnel [installing] control air tubing in the vicinity of the safety shutdown valve."
Byron 2 LER 87-018	"Byron Unit 2 was operating at 92% power when the 2B main feedwater pump tripped. The unit was ramped back to 50% power. The reactor tripped due to a low-2 steam generator level in one steam generator. All safety systems responded as designed. The cause was the inadvertent actuation of the overspeed trip plunger by a contractor working on the 2B feedwater pump high pressure stop valve."

Table A-4. Human Factors Deficiencies at Local Control Stations - Environment Deficiencies (Lighting)

Facility & Source	Description
Indian Point NRC IN 90-77 Supp. 1 2/4/91	Two fuel assemblies were inadvertently lifted because they were stuck to the upper core internals package due to bent guide pins. The bent pins were not previously detected due to ineffective lighting and camera placement. Extra lights were not placed on the reactor floor and approximately 1/2 of the lamps in the reactor cavity were burned out.
Ginna NUREG/CR-2000 LER 90-012	Turbine trip/reactor trip caused by operator dropping flashlight on turbine autostop trip relays. Attributable to poor access and lighting.
St. Lucie 1/2 EOP 88-08 EOP 88-08	"At some local sites, lighting was not adequate, thus forcing operators to carry and use flashlights. An example of this was the AFW Pump area...Another example was the Surge Tank CCW flowmeter, which, although located adjacent to a light, was too dark to read." p.10
Monticello AEOD/T706 LER 86-025	A reactor scram occurred due to work on wrong channel during a scram discharge volume surveillance test. Poor lighting in the work area contributed to the misidentification.
Farley 1/2 EOP 90-02 EOP 90-02	"...emergency lighting may not be adequate in some areas and therefore the [local actions] could not be performed without a flashlight. Similarly, ladders were not readily available for access to valves on elevated piping on some occasions."
Salem 1/2 EOP 90-80 EOP 90-80	"...identified 4 battery type emergency lights that did not operate when tested. The licensee subsequently tested 142 emergency lights and identified 11 that were out of service. The team also noted that in certain areas of the plant the normal lighting levels appeared to be marginal."
Comanche Peak EOP 89-59	"During the in-plant walkdown...the team found that emergency lighting was not available for all ERG-related equipment. The applicant's response was that an emergency lighting review had been completed recently and that problem areas were being evaluated to determine corrective actions." p.6
Palo Verde 3 NRC IN 90-69	Emergency lighting in the Main Steam Support Structure (MSSS) failed, hampering operators in their attempt to locally correct ADVs failure to operate from the control room and remote shutdown panel. In the north MSSS room, emergency lighting was mispositioned, while it was nonexistent in the South MSSS room due to a burned out bulb.

Table A-4. Human Factors Deficiencies at Local Control Stations - Environment Deficiencies (continued)

Facility & Source	Description
Farley 1 & 2 EOP 90-02 EOP 90-02	"The valve [above the main condenser] was found to be virtually inaccessible. This required the operator to place himself in a position where he could fall or otherwise hurt himself."
Ginna EOP 89-80	"...(1) the upstream trip isolation valves would require the operator to stand on a piece of angle iron (because the area was too cramped to use a ladder) and (2) the isolation valves for the steam to the turbine driven auxiliary feedwater pump require climbing over hot steam piping. The team noted that these valves could be operated, but that the hazardous conditions might cause the AO to become incapacitated."
Waterford 3 EOP 88-18	"A number of valves in the plant that must be manually operated during EOPs were inaccessible....Some of the valves were located 8 to 20 feet above ground, with no means of reaching them. In one case, operators had to locate a large aluminum ladder and set it against an overhead pipe. This task would be precarious, at best. Some valves were located about 15-20 feet above ground and behind other pipes and components. For these valves, operators must climb up and around pipes." p.15
D.C. Cook 2 IE IN 84-58 NUREG-1192 AEOD/S401	During containment spray system testing, operators closed a valve in the wrong train rendering both trains inoperable. Access is poor since both heat exchanger valves are operated with reach rods and only magic marker labels with no train identification were present.
D.C. Cook 1 NUREG-1192	During ECCS testing at full power and the "B" train SI pump out for maintenance, the operator shut the suction valves to the "A" train SI pump making both trains inoperative. The environment was hot (100 degrees Fahrenheit).

Table A-5. Human Factors Deficiencies at Local Control Stations - Communication Deficiencies

Facility & Source	Description
Fermi EOP 88-200	"The noise levels in the reactor building were generally high. These levels could be significantly higher following an accident when emergency equipment would be operating. Communications could be conducted via the plant public address system or portable radios, but effective communication could be difficult in a post-accident environment. The licensee told the team that the plant public address system was to be improved. Planned additions included multiple channels and more call stations, along with sound isolation booths in selected areas." p.13
Millstone EOP 88-10	"If both [atmospheric steam dump] valves need to be operated simultaneously, two PEOs would be required. In addition, communication is difficult due to the noise produced by the steam." p.13 "Extension cords used with headphones interfere with the PEO carrying out his task. They may get tangled in ladders or operators may trip over them." p.13
St. Lucie EOP 88-08 EOP 88-08	"Communication between the control room and a local operator were often impaired due to ambient noise levels. Page announcements may not be heard and radio communication may not be audible. One operator stated that this problem was chronic and limited his accessibility to local operators." p.10
Wolf Creek EOP 88-13	"It was also noted...that there is a potential for the operator to need communications with the control room while starting or stopping a pump. This area contains approximately five rooms, joined by one hallway. The paging system unit, located in the hallway, is provided in this area. Headsets can be used in the room, if the operator brings them." p.12

APPENDIX B
EMERGENCY OPERATING PROCEDURE INSPECTION REPORTS REVIEWED

Table B-1. Emergency Operating Procedure (EOP) Inspection Reports Reviewed (1988 Sample).

Report Number	Facility/Unit
220/88-022 410/88-023	Nine Mile Point - Unit 1
237/88-012 249/88-014	Dresden - Unit 2 Dresden - Unit 3
247/88-015	Indian Point - Unit 2
282/88-010 306/88-010	Prairie Island - Unit 1 Prairie Island - Unit 2
302/88-009	Crystal River - Unit 3
313/88-017	Arkansas Nuclear One - Unit 1
315/88-015 316/88-017	D.C. Cook - Unit 1 D.C. Cook - Unit 2
321/88-012 366/88-012	Hatch - Unit 1 Hatch - Unit 2
333/88-200	Fitzpatrick
335/88-008 389/88-008	St.Lucie - Unit 1 St.Lucie - Unit 2
336/88-010	Millstone - Unit 2
344/88-023	Trojan
361/88-013 362/88-014	San Onofre - Unit 2 San Onofre - Unit 3
382/88-018	Waterford - Unit 3
416/88-006	Grand Gulf - Unit 1
482/88-013	Wolf Creek - Unit 1

Table B-2. Emergency Operating Procedure (EOP) Inspection Reports Reviewed (1990 Sample).

Report Number	Facility/Unit
155/90-008	Big Rock Point
313/90-001 368/90-001	Arkansas Nuclear One - Unit 2
344/90-080 412/90-080	Beaver Valley - Unit 1 Beaver Valley - Unit 2
272/90-080 311/90-080	Salem - Unit 1 Salem - Unit 2
280/90-009 281/90-009	Surry - Unit 1 Surry - Unit 2
295/90-004 304/90-004	Zion - Unit 1 Zion - Unit 2
348/90-002 364/90-002	Farley - Unit 1 Farley - Unit 2
352/90-080 353/90-080	Limerick - Unit 1 Limerick - Unit 2
354/90-018	Hope Creek - Unit 1
387/90-080 388/90-080	Susquehanna - Unit 1 Susquehanna - Unit 2
395/90-023	Summer
397/90-020	WPPSS - Unit 2
424/90-008 425/90-008	Vogtle - Unit 1 Vogtle - Unit 2
443/90-084	Seabrook - Unit 1
458/90-007	River Bend - Unit 1

APPENDIX C
DATA COLLECTION AND SUMMARY FORMS

MANUAL VALVE(S) ☐ handwheel ☐ air-operated ☐ handle ☐ motor-operated ☐ chain-op	☐ no position indication ☐ missing handwheel ☐ position inferred ☐ reverse-acting ☐ positive indication ☐ difficult to operate
CONTROL(S) ☐ j-handle ☐ slide ☐ button ☐ toggle ☐ rotary ☐ key ☐ other	☐ unlabelled positions ☐ inconsistent operation ☐ inadvertent operation ☐ ambiguous indication
INDICATOR(S) ☐ meter ☐ lamp/LED ☐ gauge ☐ digital ☐ recorder ☐ other	☐ inconsistent scale ☐ inadequate graduations ☐ lamp(s) missing
PANEL: ☐ Remote S/D Panel Description:	☐ inadequate spacing ☐ lack of functional grouping ☐ no demarcation ☐ marred panel surfaces
Label Type ☐ none ☐ laminated ☐ stamped metal ☐ other_ ☐ engraved plastic	Label Deficiency ☐ poor placement ☐ illegible ☐ poor content ☐ temporary ☐ extraneous label ☐ improvised ☐ damaged
Lighting ☐ none (portable) ☐ direct ☐ indirect	Lighting Deficiency ☐ dim ☐ shadows ☐ glare
Emergency Lighting ☐ none ☐ portable ☐ permanent	Emergency Lighting Deficiency ☐ not working ☐ too distant ☐ poorly aimed
Communication Equipment ☐ PA pager ☐ not needed ☐ telephone ☐ not available ☐ sound pwr ☐ no backup ☐ radio	Communication Problems ☐ high noise level ☐ cumbersome ☐ restricted use of radio ☐ at a distance ☐ unavail. in loss of power ☐ other
Physical Access Problems ☐ height above floor ☐ keys required ☐ cramped workspace	Other Environmental ☐ heat/cold ☐ radiation ☐ humidity ☐ vibration ☐ noise

Figure C-1. Checklist used at local control stations.

SUMMARY EVALUATION SHEET

Plant: _____ Utility: _____
NSSS: _____ License: _____
AE: _____

Dimension	Human Engineering	Comment
Labeling	☐ low ☐ medium ☐ high	
Control	☐ low ☐ medium ☐ high	
Indication	☐ low ☐ medium ☐ high	
Communication	☐ low ☐ medium ☐ high	
Environment	☐ low ☐ medium ☐ high	
All Component-Level Local Control Stations	☐ low ☐ medium ☐ high	
Remote Shutdown Panels - Panel Design	☐ low ☐ medium ☐ high	
Remote Shutdown Panels - Functional Centralization	☐ low ☐ medium ☐ high	
Important Manual Valves	☐ low ☐ medium ☐ high	

Figure C-2. Summary evaluation form.

APPENDIX D
HUMAN ENGINEERING GUIDANCE RELEVANT TO LOCAL CONTROL STATIONS

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FOREWORD

The human engineering guidance contained in this appendix was compiled from a variety of sources, which are listed below:

Seminara, J.L. (1982). *Human Factors Methods for Assessing and Enhancing Power Plant Maintainability* [EPRI NP-2360]. Palo Alto, CA: Electric Power Research Institute.

Pack, R.W., Seminara, J.L., Shewbridge, E.G., & Gonzalez, W.R. (1985). *Human Engineering Design Guidelines for Maintainability* [EPRI NP-4350]. Palo Alto, CA: Electric Power Research Institute.

Bernard, T.E., Kenney, W.L., & Balint, L. (1986). *Heat-Stress-Management Program for Nuclear Power Plants* [EPRI NP-4453]. Palo Alto, CA: Electric Power Research Institute.

Seminara, J.L. (1988). *Effective Plant Labeling and Coding* [EPRI NP-6209]. Palo Alto, CA: Electric Power Research Institute.

Lewis, J.R., Morgenstern, H.M., Rideout, T.H., & Cowley, P.J. (1984). *Safety System Status Monitoring* [NUREG/CR-3621]. Washington, DC: U.S. Nuclear Regulatory Commission.

Hartley, C.S., Levy, I.S., & Fecht, B.A. (1984). *Potential Human Factors Deficiencies in the Design of Local Control Stations and Operator Interfaces in Nuclear Power Plants* [NUREG/CR-3696]. Washington, DC: U.S. Nuclear Regulatory Commission.

U.S. Department of Defense (1989). *Human Engineering Design Criteria for Military Systems, Equipment, and Facilities* [MIL-STD-1472D]. Washington, DC: Office of Management and Budget.

U.S. Nuclear Regulatory Commission (1981). *Guidelines for Control Room Design Reviews* [NUREG-0700]. Washington, DC: U.S. Nuclear Regulatory Commission.

The guidance is presented in five sections, each corresponding to a general characteristic of local control stations: labeling, indication, control, communication, and environment. The contents of and principal source(s) for each of the sections are outlined below.

Labeling - topics include the placement of labels and their content and design. Guidance in this section was compiled from EPRI NP-2360 and EPRI NP-6209.

Indication - guidance is provided regarding gauges/meters and valve position indication. Sources for this section were NUREG/CR-3621 and NUREG/CR-3696.

Control - specific guidance is limited to manual valves, since other control devices are treated in NUREG-0700. The source for manual valve guidance was MIL-STD-1472D.

Communication - guidance primarily pertains to page-party systems. The source for this section was EPRI NP-4350.

Environment - guidance is provided on various aspects of the local control station environment, e.g., temperature/humidity, noise, lighting, accessibility. Source for this section were EPRI NP-4453 (for heat/humidity considerations), EPRI NP-2360, and EPRI NP-4350.

At the start of each section, the applicability (or lack thereof) for local control stations of guidance contained in NUREG-0700 is noted. Each guidance item carries a number (reflecting the hierarchical organization of the guidance) and a brief title indicating the subject matter of the item. The guidelines are presented as simple statements of "good practice". In most cases the criteria for meeting the guidelines are clear; however, judgement will often be required in applying these general guidelines to specific situations. The additional information that follows many of the guidelines is intended to assist the user in interpreting the guidance. The document number of the source of each guideline is given after each item. (Refer to the list above for full source references). Guidance in NUREG-0700 having particular relevance to local control stations is also included within some sections, and is labeled as such. In a few cases, guidance based on practices observed during in-plant assessments is offered; the source for these items is "in-plant assessments."

This compilation does not include all of the guidance that is available. For example, some of the plants visited during the in-plant assessments had been guided in their relabeling efforts by good practices promulgated by INPO. The contents of the INPO document were not available for inclusion in the labeling section of this appendix. There are also relevant topics that are not covered in the available guidance. Radio communication is an example. Two-way radios are commonly carried by operators outside the control room as an adjunct to or substitute for the page-party systems, yet there is little guidance regarding their use.

1 LABELING

The principles reflected in the guidance in NUREG-0700 for control room labeling are often applicable at local control stations. Furthermore, it is desirable to follow the same labeling practices and conventions inside and outside the control room to avoid creating inconsistent interfaces and increasing the possibility of error.

1.1 Placement of Labels

1.1.1 Labeling of Equipment

All components and systems with which operators may interact should be labeled.
SOURCE: EPRI NP-2360

1.1.2 Replacement of Labels

When labels are placed, earlier markings (labels applied during construction or acceptance, informal labels) should be removed.
SOURCE: EPRI NP-6209

1.1.3 Viewing Direction

When equipment may be approached from more than one direction, labels should be placed on surfaces visible from each direction.
SOURCE: EPRI NP-6209

1.1.4 Label Visibility

Identifying labels should be placed so that they are readily visible at typical viewing distances and orientations.
ADDITIONAL INFORMATION: Labels should be placed so as to be visible to plant personnel of both short and tall stature.
SOURCE: EPRI NP-2360, EPRI NP-6209

1.1.5 Locator Labels

When components are partially blocked from view, readily visible markings indicating their location and identity should be placed nearby.
ADDITIONAL INFORMATION: The location of overhead valves can be indicated by labels on floors or walls directly below them.
SOURCE: EPRI NP-6209

1.1.6 Label Orientation

Labels should be designed and hung so that text is oriented horizontally for ease of reading.
ADDITIONAL INFORMATION: Requiring operators to manipulate and re-orient the label is inconvenient (especially when their hands are full), and may lead to misreading.
SOURCE: EPRI NP-6209, EPRI NP-2360

1.1.7 Label Positioning

Labels should be attached or positioned so as to unambiguously indicate the item being identified.
SOURCE: EPRI NP-2360

1.1.8 Redundant Labels
When labels are placed on the doors of equipment cabinets, redundant labels should be placed inside so that they are visible when the door is open.
SOURCE: EPRI NP-6209

1.1.9 Label Placement Conventions
Specific conventions for label placement should be established for each type of equipment (e.g., valves, motors).
SOURCE: EPRI NP-6209

1.1.10 Label Mounting
Tags should be attached to components so as not to cause damage or interfere with operation.
ADDITIONAL INFORMATION: Valve labels should not be connected to handwheels or operating chains. The wire used to attach a label to a valve should be passed through the yoke in a manner that will not damage the stem. For chain-operated valves, the label should be wired to a small piece of plastic pipe through which the operating chain passes freely.
SOURCE: EPRI NP-6209

1.1.11 Label Replacement after Maintenance
Maintenance procedures should require personnel to check that labels are in place after components are reassembled or replaced.
SOURCE: EPRI NP-6209

1.1.12 Means of Label Attachment
Labels and tags should be securely attached in a manner appropriate to the equipment and environmental conditions.
ADDITIONAL INFORMATION: The method chosen to attach a label should take into account the possibility of exposure to heat, corrosive substances, oil, or solvents.
SOURCE: EPRI NP-2360

1.2 Label Design

1.2.1 Label Material
The material from which labels and tags are made should be appropriate to the equipment and environmental conditions.
ADDITIONAL INFORMATION: The material chosen should take into account the possibility of exposure to heat, corrosive substances, oil, or solvents. A single label material may not be appropriate in all environments. If different label material is required at different locations in the plant, an effort should be made to keep the content and format of the labels constant.
SOURCE: in-plant assessments

1.2.2 Label Contrast
Lettering and background colors should be chosen to provide high contrast and high legibility.
ADDITIONAL INFORMATION: Dark letters on a light background are preferred. NUREG-0700 (exhibit 6.6-9) provides examples of color combinations and their relative legibility. Stamped metal tags (brass, stainless steel, color anodized aluminum) often are illegible under less-than-optimal conditions.
SOURCE: EPRI NP-6209, EPRI NP-2360

1.2.3 Character Height

Characters used on labels should be sized to take into account viewing distances and illumination conditions.

ADDITIONAL INFORMATION: The character height recommendations in NUREG-0700 (section 6.6.4.1, item a) should be observed. Character heights required for various viewing distances are given in Table D-1. Under less-than-optimal viewing conditions, the preferred values should be used as minimums. The preferred values should also be used for critical markings associated with safety-related systems.

SOURCE: EPRI NP-6209, EPRI NP-2360

1.2.4 Stenciled Labels

The use of stenciled labels should be avoided.

ADDITIONAL INFORMATION: The gaps in stenciled characters render them less legible than other forms of labeling.

SOURCE: EPRI NP-6209

1.2.5 Character Spacing Guidance

The character spacing guidelines in NUREG-0700 should be observed (section 6.6.4.2, item d).

SOURCE: EPRI NP-6209

1.2.6 Label Reflectance

Surfaces of labels should have a non-reflective (i.e., matte) finish.

ADDITIONAL INFORMATION: Reflective materials may be added to labels to aid locating equipment when normal lighting is lost. Such labels should be designed so that legibility is not impaired under normal lighting conditions, e.g., a reflective border may be placed around the contents of the label.

SOURCE: EPRI NP-6209

1.3 Label Content

1.3.1 Label Information

Labels should contain concise, descriptive noun names along with alphanumeric system and component identification codes.

ADDITIONAL INFORMATION: Labels should provide sufficient descriptive information to allow the least experienced operator to recognize the equipment. The following additional items may be considered for inclusion on labels: unit/train/channel designations, power supply information, operational characteristics, and flow direction.

SOURCE: EPRI NP-6209, EPRI NP-2360

1.3.2 Labeling Conventions

Labeling conventions should be established to ensure consistency of plant labeling with drawings and procedures.

SOURCE: EPRI NP-6209, EPRI NP-2360

1.3.3 Standard Label Format

The format of presentation (e.g., order, position) of information should be consistent on all labels.

SOURCE: EPRI NP-6209

1.3.4 Abbreviations

Abbreviations used on labels should be standardized and easily recognized.
SOURCE: EPRI NP-2360

2 INDICATION

Indicators (meters, gauges, indicator lights, counters and recorders) located outside the control room should conform to the general principles and guidelines contained in Section 6.5 - Visual Displays of NUREG-0700. When NUREG/CR-3696 was prepared, references to CRT displays in NUREG-0700 (e.g., in Section 6.7 - Process Computers) were not considered applicable to local control stations (Hartley et al., 1984). However, CRTs are currently used outside the control room and computer-based technology at local control stations is likely to increase in the future. Accordingly, guidance in NUREG-0700 regarding CRT displays (e.g., Section 6.7.2) may be relevant to the evaluation of indication at local control stations in newer plants or in the case of recent backfits.

2.1 Gauges/Meters

2.1.1 Design

The design of gauges and meters should conform to the relevant sections of NUREG-0700 (e.g., Sections 6.5.1 and 6.5.2).
SOURCE: NUREG/CR-3696

2.2 CRT Displays

2.2.1 Design

If CRT displays are employed, they should conform to the relevant sections of NUREG-0700 (i.e., Section 6.7.2).
ADDITIONAL INFORMATION: Guidance for CRT display design in NUREG-0700 is limited. Accordingly, NUREG-0700 is being revised and extended.
SOURCE: NUREG/CR-3696

2.3 Valve Position Indication

2.3.1 Alignment Marks

Alignment marks should be used to indicate open and closed status of important manual valves.
SOURCE: NUREG/CR-3621

2.3.2 Visibility of Position Indication

The location and size of the alignment marks should consider the normal viewing distance, location, and ambient lighting.
SOURCE: NUREG/CR-3621

2.3.3 Indication of Full Open/Closed Positions

Alignment marks should show both the valve's fully open and fully closed positions.
SOURCE: NUREG/CR-3621

2.3.4 Design of Position Indication

Alignment marks should be located to minimize parallax error.

ADDITIONAL INFORMATION: Parallax refers to the apparent change in the relative positions of objects depnding on the position of the viewer. Error will be minimized if the distance between the indicator and the marks against which it is to be read is small and if the indicator is located so that it can be viewed "straight-on", i.e., with the observer's line of sight perpendicular to the plane of the alignment marks.

SOURCE: NUREG/CR-3621

2.3.5 Indication of Direction of Rotation

In cases where the direction of rotation of a valve control wheel is not obvious, the direction of rotation for opening and closing should be indicated.

SOURCE: NUREG/CR-3621

2.3.6 Precision of Indication

Alignment marks should be precise enough that the observers can tell when a valve is fully opened or closed.

SOURCE: NUREG/CR-3621

2.3.7 Alternate Means of Local Position Indication

For those valves where alignment marks would not be appropriate, consideration should be given to indicators that are activated by valve limit controls.

SOURCE: NUREG/CR-3621

3 CONTROL

Many of the types of controls treated in Section 6.4 - Controls of NUREG-0700 are used at local control stations, especially at multifunction panels (Hartley, et al., 1984). Much of the guidance is, therefore, applicable to local control stations. Hartley et al. point out that guidance relevant to single-function local control stations (notably manual valves) is lacking in NUREG-0700. A table of handwheel specifications from MIL-STD-1472C is reproduced in NUREG/CR-3696.

3.1 General

3.1.1 Design of Controls

The design and operation of controls should conform to the relevant sections of NUREG-0700.
SOURCE: NUREG/CR-3696

3.1.2 Inadvertent Activation

Controls should be protected against inadvertent actuation (see NUREG-0700, section 6.4.1.2).
ADDITIONAL INFORMATION: The danger of inadvertent actuation of controls may be greater outside the control room due to ongoing construction, maintenance, calibration, outage-related activities. Controls can be affected by personnel or equipment moving by, radio transmissions, vibration, etc.
SOURCE: NUREG-0700

3.1.3 Suitability for Operator Use

If protective clothing may be required, the operation of controls should be compatible with its use (see NUREG-0700, section 6.4.1.1. c,d).
ADDITIONAL INFORMATION: The likelihood of operators requiring protection (e.g., against heat or radiation) is greater outside the control room.
SOURCE:NUREG-0700

3.2 Manual Valves

3.2.1 Operating Labels

Handwheels should be provided with double-ended arrows showing the direction of operations and labeled at each end to indicate the functional result (i.e., open and close).
SOURCE: MIL-STD-1472D

3.2.2 Turning Aids

Knurling, indentation, high-friction covering, or a combination of these should be built into the handwheel to allow the application of maximum torque.
SOURCE: MIL-STD-1472D

4 COMMUNICATION

Much of the guidance provided in NUREG-0700 regarding voice communications systems (section 6.2.1) is relevant to local control stations (Hartley et al., 1984).

4.1 Loudspeakers

4.1.1 Range of Coverage of Loudspeakers

Coverage should be such that members of the work force can be alerted reliably and without excessive attempts under all plant conditions.
SOURCE: EPRI NP-4350

4.1.2 Coverage Areas of Loudspeakers

Loudspeaker coverage should be provided in all areas where the work force may be.
SOURCE: EPRI NP-4350

4.1.3 Locations and Amplitudes of Loudspeakers

Speakers should be placed within a space so that their number, location, and volume provide an adequate signal to all workers therein.
ADDITIONAL INFORMATION: Room size and configuration and ambient noise levels should be taken into account.
SOURCE: EPRI NP-4350

4.1.4 Echoes

Sufficient numbers of loudspeakers should be provided in containment and other large volumes to avoid excessive echoing.
ADDITIONAL INFORMATION: Maximum speaker range in these reverberant spaces should not exceed 50 feet.
SOURCE: EPRI NP-4350

4.2 Public Address/Pager Stations

4.2.1 Locations of Page Stations

Page stations should be located so that time required for access by personnel does not generally exceed 30 seconds.
SOURCE: EPRI NP-4350

4.2.2 Shielding of Page Stations

Sound shielding should be provided where ambient noise levels exceed 90 dBA.
SOURCE: EPRI NP-4350

4.2.3 Control of Page System

Design features or administrative controls should limit unauthorized or excessive paging.
SOURCE: EPRI NP-4350

4.2.4 Variable Amplitude Speakers

A means of varying speaker amplitude should be provided when ambient noise levels may vary by more than 20dB.

ADDITIONAL INFORMATION: Features should be provided to allow the volume setting to be monitored. Administrative controls should be established to ensure that speaker amplitude is restored after having been reduced, e.g., during an outage.

SOURCE: EPRI NP-4350

4.3 High Noise Areas

4.3.1 Speech Conditioning

Speech conditioning should be provided for paging systems with loudspeakers in noisy areas where intelligibility is poor.

ADDITIONAL INFORMATION: Various techniques are available for modifying the electrical signal representing speech so as to enhance the intelligibility of the output. Additional treatment, such as noise shielding, should be provided where the microphone is also in a noisy area so that its signal-to-noise output does not exceed 10 dB.

SOURCE: EPRI NP-4350

4.3.2 Mouthpiece Characteristics

Noise-cancelling microphones, mouth-piece noise shields, and contact microphones should be provided where needed in noise environments of 85 dBA and above.

SOURCE: EPRI NP-4350

4.3.3 Headsets

Noise-attenuating headsets should be provided for noise areas of 85 dBA and above.

ADDITIONAL INFORMATION: Guidelines on headsets are given in NUREG-0700, section 6.2.1.3 b.

SOURCE: EPRI NP-4350

4.3.4 Portable Alerting Devices

Personal page devices suitable for high-noise or remote areas should be provided.

SOURCE: EPRI NP-4350

4.4 Two-Way Communication Systems Design Guidance

4.4.1 Capacity Requirements

A minimum of five communications channels should be provided to avoid excessive waiting for a free channel.

SOURCE: EPRI NP-4350

4.4.2 Dedicated Emergency Circuits

Dedicated lines should be provided for frequent or emergency communications.

ADDITIONAL INFORMATION: Sound-powered lines are a cost-effective method of providing this capability.

SOURCE: EPRI NP-4350

4.4.3 Signal Characteristics
The signal transmission characteristics of the system should support good intelligibility at reasonable cost.
SOURCE: EPRI NP-4350

4.4.4 System Access Locations
System stations should be located so that time and effort required for access by personnel is not excessive and so that stations are in areas of relative quiet.
SOURCE: EPRI NP-4350

4.4.5 Portable Communication Devices
Portable systems should be available to supplement installed systems.
ADDITIONAL INFORMATION: Guidelines for the use of portable radio transceivers (walkie-talkies) are given in NUREG-0700, section 6.2.1.4.
SOURCE: EPRI NP-4350

4.4.6 Radio Coverage
Surveys should be conducted to identify areas in which radio communication is not possible, e.g., "dead spots" or areas near sensitive equipment.
ADDITIONAL INFORMATION: Other means of communication should be readily available in areas where radio use is prohibited.
SOURCE: in-plant assessments

4.4.7 Radio Repeaters
Radio repeaters should be installed to eliminate "dead spots" if radio communication with operators is relied upon.
SOURCE: in-plant assessments

4.4.8 Use with Special Garments
Communication capability should be provided for personnel wearing protective clothing.
ADDITIONAL INFORMATION: Voice communication with masks is considered in NUREG-0700, section 6.2.1.8.
SOURCE: EPRI NP-4350

4.5 Administrative Considerations

4.5.1 Training in Communications Practices
Communications training should be provided as a cost effective method of improving efficiency and reliability of communications.
SOURCE: EPRI NP-4350

4.5.2 Periodic Surveillance Programs
Administrative programs should provide for periodic system surveillance.
SOURCE: EPRI NP-4350

4.5.3 Intelligibility Tests

Determinations of speech intelligibility should be conducted for activities involving critical communications.

SOURCE: EPRI NP-4350

4.5.4 Page System Capacity Upgrading

Multiplexing should be added where needed to expand the number of page-party channels.

SOURCE: EPRI NP-4350

5 ENVIRONMENT

Much of the guidance contained in NUREG-0700 regarding noise, temperature/humidity, lighting, etc. is **not** applicable to the diverse environments encountered at local control stations.

5.1 Temperature/Humidity

5.1.1 Outdoor Equipment

Equipment located out-of-doors should be sheltered from the elements as much as possible.
SOURCE: EPRI NP-2360

5.1.2 Heat Stress

In assessing the danger posed to operators by heat exposure, the level of physical activity and the protective clothing required by the task should be considered in addition to the temperature and humidity conditions.
ADDITIONAL INFORMATION: The amount of metabolic heat being generated by the operator and the restriction of evaporative heat loss associated with protective clothing are important considerations. The assessment of heat stress is treated in detail in EPRI NP-4453.
SOURCE: EPRI NP-4453

5.1.3 Engineering Controls

Where heat may impair the effectiveness or threaten the well-being of operators, engineering controls should be applied.
ADDITIONAL INFORMATION: Examples of engineering controls include: shielding or insulating sources of radiant heat, eliminating steam leaks, increasing ventilation, providing assists to reduce the strenuousness of the task, etc.
SOURCE: EPRI NP-4453

5.1.4 Work Practices

Where risks due to heat exposure cannot be eliminated by engineering controls, work practices should be adopted to minimize the risk.
ADDITIONAL INFORMATION: Work practices recommended by EPRI NP-4453 include training in the recognition and treatment of heat illnesses, water and salt replacement, acclimation, and work/rest cycles (stay times). Illustrations of how temperature, metabolism, and clothing relate to stay times are found in Tables E-2 and E-3. EPRI NP-4453 should be consulted regarding the assessment of heat stress.
SOURCE: EPRI NP-4453

5.1.5 Water Replacement

Water should be readily available in areas where the potential exists for heat stress.
ADDITIONAL INFORMATION: Unusual measures may be necessary to provide drink to workers restricted areas.
SOURCE: EPRI NP-4453

5.2 Noise

5.2.1 Hearing Protection

Ear protection devices should be available and required to be worn in areas where noise levels are 85 dB or more.
SOURCE: EPRI NP-2360

5.2.2 Sound Attenuating Enclosures

When operators may be required to remain in high noise areas for extended periods of time, appropriate sound attenuating enclosures should be provided.
SOURCE: EPRI NP-2360

5.2.3 Auditory Capabilities of Users

The hearing sensitivity of the work force should be monitored.
ADDITIONAL INFORMATION: The needs of those workers with hearing degradation should be taken into account.
SOURCE: EPRI NP-4350

5.2.4 Communications and Hearing Potection

Communication equipment in high noise areas should be compatible with ear protection devices.
SOURCE: EPRI NP-4350

5.3 Lighting

5.3.1 Portable Lighting

Easily used, portable lighting devices should be readily available nearby when permanent lighting (normal or emergency) may be inadequate.
SOURCE: EPRI NP-2360

5.4 Accessibility

5.4.1 Permanent Means of Access

When equipment requiring recurrent or emergency operation is beyond the normal standing reach of operators, permanent means of access should be provided.
ADDITIONAL INFORMATION: Examples of access provisions include work platforms, ladders, etc.
SOURCE: EPRI NP-2360

5.4.2 Temporary Means of Access

When equipment is located beyond the normal standing reach of operators and permanent access provision is not feasible, temporary or movable access platforms should be available.
SOURCE: EPRI NP-2360

5.4.3 Formal Means of Access

Catwalks, ladders and other formal means should be provided for operators to reach equipment.
ADDITIONAL INFORMATION: Operators should not be required to walk along pipes or to use components as "stepping stones" in order to reach equipment.
SOURCE: EPRI NP-2360

5.4.4 Sufficient Clearance

Sufficient clearance should be provided in the vicinity of equipment in contaminated or high temperature areas to allow operators easy access despite the use of protective garments and associated gear.
SOURCE: EPRI NP-2360

5.4.5 Impediments to Access

Access to equipment to be operated should not be impeded by structural elements.
ADDITIONAL INFORMATION: Structural elements added to the plant (e.g., seismic reinforcements) should not restrict access to equipment.
SOURCE: EPRI NP-2360

Table D-1. Minimum and preferred character heights for various viewing distances.

VIEWING DISTANCE	MINIMUM CHARACTER HEIGHT		PREFERRED CHARACTER HEIGHT	
	inches[1]	points[2]	inches[3]	points[2]
28 inches	0.112	8	0.168	12
3 feet	0.144	10	0.216	16
4 feet	0.192	14	0.288	21
5 feet	0.240	17	0.360	26
6 feet	0.288	21	0.432	30
10 feet	0.480	35	0.720	50
20 feet	0.960	70	1.440	100
30 feet	1.440	100	2.160	150
40 feet	1.920	140	2.880	200
50 feet	2.400	175	3.600	250

[1] minimum character height = distance x .004

[2] character heights in points (1 point = 1/72 in) are approximate

[3] preferred character height = distance x .006

Table D-2. Stay times for different WBGTs by combinations of clothing and metabolism (from EPRI NP-4453).

WBGT (Botsball)		Work Clothes			Cotton Coveralls			Double Cottons			Cottons plus Plastics		
		Metabolism			Metabolism			Metabolism			Metabolism		
C	F	Low	Mod	High	Low	Mod	High	Low	Mod	High	Low	Mod	High
50 (47)	122 (116)	15-30	0-10		5-15	0-5		5-15					
48 (45)	118 (112)	20-45	5-15		15-30	5-10		10-20			5-15		
46 (43)	115 (109)	20-45	5-20		20-45	5-15		15-30	0-10		15-20		
44 (41)	111 (105)	30-60	10-25		20-45	5-20		20-45	5-15		15-30	0-10	
42 (39)	108 (102)	45-90	15-30	5-10	30-60	10-25		20-45	5-20		20-45	5-15	
40 (37)	104 (99)	60-90	15-45	10-20	45-90	15-40	5-10	30-60	10-25		20-45	5-20	
38 (35)	100 (95)	90-120	20-45	15-30	60-90	15-45	10-25	45-90	15-30	5-10	30-60	10-25	
36 (33)	97 (92)	2h-4h	30-60	15-40	90-120	25-45	15-30	60-90	15-45	10-20	45-90	15-30	5-10
34 (31)	93 (88)	3h-8h	45-90	20-45	2h-4h	30-60	15-45	90-120	20-45	15-30	60-90	15-45	10-20
32 (29)	90 (85)	NL	90-120	30-60	3h-8h	60-100	25-50	2h-4h	30-60	15-40	90-120	20-45	15-30
30 (27)	86 (81)	NL	2h-4h	60-120	NL	1h-2h	30-90	3h-8h	45-90	20-45	2h-4h	30-60	15-40
28 (26)	82 (78)	NL	NL	2h-4h	NL	1h-4h	lo-3h	NL	90-120	30-60	3h-8h	45--90	20-45
26 (24)	79 (75)	ML	NL	4h-8h	NL	NL	3h-8h	NL	2h-4h	60-120	NL	90-120	30-60
24 (22)	75 (71)	NL	NL	NL	NL	NL	NL	NL	NL	2h-4h	NL	2h-4h	60-120
22 (20)	72 (68)	NL	NL	NL	NL	NL	NL	NL	NL	4h-8h	NL	NL	2h-4h
20 (18)	68 (64)	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	4h-8h
<20	<68	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL

Table D-3. Ranges of WBGT for different ranges of stay times by combinations of clothing and metabolism (from EPRI NP-4453).

Stay Time	Work Clothes			Cotton Coveralls			Double Cottons			Cottons plus Plastics		
	Metabolism			Metabolism			Metabolism			Metabolism		
(min)	Low	Mod	High	Low	Mod	High	Low	Mod	High	Low	Mod	High
0-15	50-52	42-50	38-42	48-50	41-49	37-41	46-46	38-46	34-38	44-46	36-44	32-36
	(122-126)	(108-122)	(100-108)	(118-122)	(106-120)	(99-106)	(115-118)	(100-115)	(93-100)	(111-115)	(97-111)	(90-97)
15-30	44-50	36-42	32-38	42-48	35-41	31-37	40-46	32-38	28-34	38-44	30-36	26-32
	(111-122)	(97-108)	(90-100)	(108-118)	(95-106)	(89-99)	(104-115)	(90-100)	(82-93)	(100-111)	(86-97)	(79-90)
20-45	42-48	34-38	31-34	40-46	33-37	30-33	38-44	30-34	27-30	36-42	28-32	25-28
	(108-118)	(93-100)	(89-93)	(104-115)	(91-99)	86-91)	(100-111)	(86-93)	(81-86)	(97-108)	(82-90)	(77-82)
30-60	40-44	33-36	30-32	38-42	32-35	29-31	36-40	29-32	26-28	34-38	27-30	24-26
	(104-111)	(91-97)	(86-90)	(100-108)	(90-95)	(84-69)	(97-104)	(84-90)	(79-82)	(93-100)	(81-86)	(75-79)
45-90	38-42	32-34	29-31	36-40	31-33	28-30	34-33	28-30	25-27	32-36	26-28	23-25
	(100-108)	(90-93)	(84-89)	(97-104)	(89-91)	(82-86)	(93-100)	(82-86)	(77-81)	(90-97)	(79-82)	(73-77)
60-120	36-40	30-33	28-30	34-38	29-32	27-29	32-36	26-29	24-26	30-34	24-27	22-24
	(97-104)	(86-91)	(82-86)	(93-100)	(84-90)	(81-84)	(90-97	(79-84)	(75-79)	(86-93)	(75-81)	(72-75)
90-3h	34-38	29-32	27-31	32-36	28-31	26-30	30--34	25-28	23-27	28-32	23-26	21-25
	(93-100)	(84-90)	(81-89)	(90-97)	(82-89)	(79-86)	(86-93)	(77-82)	(73-81)	(82-90)	(73-79)	(70-77)
2h-4h	32-36	28-30	26-28	30-34	27-29	25-27	28-32	24-26	22-24	26-30	22-24	20-22
	(90-97)	(82-86)	(79-82)	(86-93)	(81-84)	(77-81)	(82-90)	(75-79)	(72-75)	(79-86)	(72-75)	(68-72)

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10. SUPPLEMENTARY NOTES

11. ABSTRACT *(200 words or less)*

The objective of this research project was to evaluate current human engineering at local control stations (LCSs) in nuclear power plants, and to identify good human engineering practices relevant to the design of these operator interfaces. General literature and reports of operating experience were reviewed to determine the extent and type of human engineering deficiencies at LCSs in nuclear power plants. In-plant assessments were made of human engineering at single-function as well as multifunction LCSs. Besides confirming the existence of human engineering deficiencies at LCSs, the in-plant assessments provided information about the human engineering upgrades that have been made at nuclear power plants. Upgrades were typically the result of any of three influences - regulatory activity, broad industry initiatives such as INPO, and specific in-plant programs (e.g., activities related to training). It is concluded that the quality of LCSs is quite variable and might be improved if there were greater awareness of good practices and existing human engineering guidance relevant to these operator interfaces, which is available from a variety of sources. To make such human engineering guidance more readily accessible, guidelines were compiled from such sources and included in the report as an appendix.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*

Human Factors Engineering - Control Equipment, Man-Machine Systems - Nuclear Power Plants, Nuclear Power Plants - Human Factors Engineering, Cybernetics, Failures, Human Factors, Failures, Personnel, Reactor Instrumentation, Reactor Control Systems, Safety Engineering

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