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Potential Human Factors Deficiencies in the Design of Local Control Stations and Operator Interfaces in Nuclear Power Plants

repared by C. S. Hartley, I. S. Levy, B. A. Fecht

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ABSTRACT

The Pacific Northwest Laboratory has completed a project to identify human factors deficiencies in safety-significant control stations outside the control room of a nuclear power plant and to determine whether NUREG-0700, "Guidelines for Control Room Design Reviews," would be sufficient for reviewing those local control stations (LCSs). The project accomplished this task by first, reviewing existing data pertaining to human factors deficiencies in LCSs involved in significant safety actions; second, surveying LCSs environments and design features at several operating nuclear power plants; and third, assessing the results of that survey relative to the contents of NUREG-0700. The study's conclusions are 1) a definitive list of safety-significant local control stations cannot be specified because power plant designs vary significantly; 2) most, if not all, local control stations have design deficiencies that could be corrected by applying human factors engineering principles; and 3) NUREG-0700 is generally applicable to LCSs but that guidance is needed to address the design of manually operated valves and the design requirements of LCSs in extreme environmental conditions. Finally, the study recommends an approach for improving present LCSs to reduce the likelihood that operator error will occur.

EXECUTIVE SUMMARY

The Pacific Northwest Laboratory has completed a project to identify human factors deficiencies in safety-significant control stations outside the control room of a nuclear power plant and to determine whether NUREG-0700, "Guidelines for Control Room Design Reviews," provides a methodology sufficient for reviewing those local control stations (LCSs). The first step of the project was to establish a knowledge base by identifying which local control stations or other interfaces are involved in significant safety actions, identifying transient and accident scenarios that may affect environmental conditions at local control stations, and determining what human factors deficiencies exist in the design of those interfaces.

The identification of those LCSs involved in significant safety actions was established by examining NRC regulatory documents and systems manuals, interviewing operator licensing examiners, and visiting one operating nuclear power plant. Transient and accident scenarios were established by reviewing a recent report on abnormal and emergency Nuclear Power Plant (NPP) operating events. Background information on human factors deficiencies related to local control stations was established by reviewing documents from the Institute of Nuclear Power Operations (INPO), the Electric Power Research Institute (EPRI), the Nuclear Regulatory Commission (NRC), and the U.S. Department of Labor (DOL).

This review of existing data resulted in the conclusion that a definitive list of safety-significant local control stations cannot be specified because power generating system designs vary significantly from plant to plant. The local control stations having safety significance are 1) those that are manned when the control room is evacuated, 2) those required to monitor and control postaccident H_2 levels or routine plant radiation releases, or 3) those that may affect reactor containment integrity, shutdown, and accident mitigation. Some examples of local control station functions that would fit this general definition (in most cases) are remote shutdown, remote reactor scram, diesel generator, vital electrical systems (switchgear), emergency coolant injection, containment H_2 sampling, and radwaste monitoring and control.

The second project step was to survey local control stations at several representative nuclear power plants. The survey method used was to interview a local control station operator at each LCS visited and to make environment measurements and take photographs for later analysis. Eleven different LCSs were examined at four different plants (1 BWR and 3 PWRs). The survey results revealed that local environmental conditions of noise, temperature, and humidity tended to fall outside of accepted values for comfort zones, though not generally at extremes. These conditions do not present operational problems unless the station must be manned for long periods or unless protective garments must be

worn to reduce radiation exposure. Only sound levels at the diesel generator panels could be considered to be hazardous to the health of the unprotected operator. A number of human factors design deficiencies of local control stations were discovered from the interviews and photographic analysis. These deficiencies tended to be common to all types of local control stations: poor labeling practices, poor LCS maintenance and housekeeping, and component designs that did not comply with accepted human factors standards. In addition, a number of specific deficiencies were noted at the individual LCSs studied.

The third project step was to assess the adequacy of NUREG-0700 for application to local control stations and the human factors deficiencies found at LCSs. To accomplish this, each section of NUREG-0700 was evaluated in relation to the results of the plant survey. Most parts of NUREG-0700 were judged to be at least partially applicable to LCSs. Only two areas of deficiency were found: first, the NUREG does not provide design guidance for manually-controlled valves; and second, the NUREG does not present information on design adaptations dictated by extreme environmental conditions. Alternative sources of guidance covering these two deficiencies were found in the Human Engineering Guide for Equipment Design (VanCott and Kinkade, 1972) and a military standard (MIL-STD-1472C).

Several suggestions for making quick fixes are detailed in Section 6.1. These suggestions include analyzing the operator's job to accurately assess workload and equipment needs; improving the workspace by providing seating, laydown areas for written procedures, and close access to auxiliary components; improving the control panel design by fixing labels and adhering to population stereotypes; improving conditions and equipment for better communications; providing procedures at the LCS; installing equipment to improve environmental conditions; and upgrading LCS maintenance and housekeeping.

A reasonable long-term approach to improving the human factors design of local control stations is to require the involvement of human factors experts throughout the design and life cycles of future plants.

One area of future concern for local control station human factors is the allocation of system functions between the operator and machines in semi-automated systems. As more and more functions are given to the machine, the operator's role in the system changes so that he may no longer be able to effectively respond to emergency conditions when they occur. New research should be performed to aid future nuclear power plant designers and regulators in assessing the hazards that may develop in high-technology local control stations installed as retrofits in old plants or incorporated into new plant designs.

To eliminate much of the human error in the operation of existing safety-related LCSs, this study recommends the following actions:

1. Each plant should be analyzed to determine which local control stations are safety related.

2. Appropriate human factors design guidelines should be applied to correct the human factors deficiencies of those safety-related LCSs.

3. Such guidelines should be applied through a "quick fix" approach that addresses the commonly occurring LCS deficiencies identified in this study.

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POTENTIAL HUMAN FACTORS DEFICIENCIES IN THE DESIGN OF LOCAL CONTROL STATIONS AND OPERATOR INTERFACES IN NUCLEAR POWER PLANTS

1.0 INTRODUCTION

The Nuclear Regulatory Commission (NRC) published NUREG-0700, "Guidelines for Control Room Design Reviews," for evaluating the human factors engineering (HFE) of main control rooms in nuclear power plants. Many control stations and operator interfaces necessary for plant operations are placed outside of the main control room -- local control stations (LCSs). These local control stations, which may range from a single valve wheel to a multiple-function control panel, are not specifically addressed by NUREG-0700 or any other HFE guidance concerning the interface between the operator (usually an auxiliary reactor operator) and the control equipment.

The experience of the Human Factors Engineering Branch of the NRC's Division of Human Factors Safety suggests that some local control stations are poorly designed and may cause operators to commit errors. Errors in the operation of some local control stations (a radiation waste control panel or remote reactor shutdown panel, for instance) could have serious consequences for public safety. The NRC asked the Pacific Northwest Laboratory (PNL) to examine local control stations having safety significance and to determine whether the HFE standards of NUREG-0700 could be applied to these LCSs as well as to the main control room of a nuclear power plant. The Pacific Northwest Laboratory is operated for the U.S. Department of Energy by Battelle Memorial Institute.

The principal goals of this study were: 1) to search out existing data on human factors deficiencies in LCSs that involve significant safety actions; 2) to assess whether the human factors design of these safety-significant LCSs is indeed a problem at current nuclear power plants, and 3) to determine whether NUREG-0700 could be used in evaluating and improving these LCSs.

The study focused on the LCSs that are judged to be significant to plant and public safety. These LCSs were identified by reviewing existing studies and regulations to find information relating local control stations, auxiliary operator interfaces, and human factors. This Review of Existing Data is described in Section 3.0 of this report.

Once the data review had indicated what kinds of LCSs were likely to be significant to safety, we visited several power plants to examine a sample of local control stations and identify any deficiencies in the human factors design of these stations. This Survey of Local Control

Stations at Several Power Plants is reported in Section 4.0.

Section 5.0 of this report assesses the adequacy of NUREG-0700 for application to local control stations. The discussion relates the kinds of HFE deficiencies we found to the standards presented in NUREG-0700 and elsewhere. Section 6.0 outlines some suggestions for improving the human factors design of local control stations, including some relatively "quick fixes" that could solve many of the HFE deficiency problems identified during the plant visits.

As utilities make more use of human factors evaluations during plant design, the kinds of LCS design deficiencies we found during our survey should occur less frequently at future power plants. One area that is likely to generate more problems in the future is increased automation. Section 6.3 discusses the implications of Problems Anticipated with Future Local Control Stations.

Section 2.0 of this document summarizes the principal Conclusions and Recommendations that have resulted from the above tasks.

2.0 CONCLUSIONS AND RECOMMENDATIONS

The study consisted of the following tasks:

1. Identify which local control stations are involved in significant safety actions.

2. Refer to likely sources of power plant data (for example, licensee event reports) to determine what human factors deficiencies are known to exist in the design of these interfaces.

3. Survey a sample of local control stations at representative nuclear power plants, collecting environmental, interview, and pictorial data for human factors analysis.

4. Use the survey data to identify human factors deficiencies in the design of current local control stations.

5. Assess whether NUREG-0700 could be applied to evaluate local control stations and adequately reduce the number of HFE design deficiencies.

6. Indicate some methods of improving the HFE design of local control stations.

Completion of these tasks has led to the following conclusions and recommendations.

2.1 CONCLUSIONS

2.1.1 Safety-Significant Local Control Stations

A definitive list of safety-significant LCSs cannot be specified because power plant designs vary so much. Each design has a different set of LCSs, and the safety significance of the control stations differs from plant to plant.

Because specific definitions were inappropriate, we developed a general definition of the local control stations that have safety significance: 1) those LCSs that will be manned when the control room is evacuated, 2) those required to monitor and control postaccident containment H_2 levels or routine plant radiation releases, or 3) those that may affect reactor integrity, shutdown, and accident mitigation. In most cases, the domain of safety-related LCSs would include remote shutdown, remote reactor scram, diesel generator, vital electrical systems (switchgear), emergency coolant injection, containment H_2 sampling, and radwaste monitoring and control.

2.1.2 Human Factors Deficiencies of Local Control Stations

The review of existing power plant data provided no real human factors data related specifically to local control stations. One primary source, plant evaluations from the Institute of Nuclear Power Operations, proved to be too general for significant use in this study. A limited analysis of licensee event reports (LERs) did reveal problems involving inadvertent activation of controls.

Conclusions from the in-plant survey of safety-significant local control stations are necessarily qualified by the limited scope of the study: we visited only five power plants and gathered specific data on only 11 different local control stations. This sample cannot be considered statistically representative of local control stations at U.S. nuclear plants. Yet the general conclusions below are consistent with our experiences at many other nuclear plants and with the experiences of the NRC's Human Factors Engineering Branch.

- The human factors design of some local control stations at a few nuclear plants is adequate for the required task; at many others it is very poor. The control panels we examined were so variable in their quality and their features that it was not even possible to compare two panels with the same functions. The wide range found probably reflects the high variability of nuclear plant designs in the U.S.

- The human factors deficiencies observed at many of the local control stations are of the sort that can be expected to lead to operator errors.

- Many of the human factors deficiencies would be simple to correct: poor design and maintenance of identifying labels and markings; no procedures located at the control station. Other deficiencies would not be so simple to correct: poor component design; illogical arrangement of controls.

- The environmental conditions measured at some local control stations were outside of accepted human factors limits for a good working environment. Some of these conditions (for example, poor lighting) could lead to reduced efficiency or operator errors at any time. Others (for example, high temperatures or excessive noise) might become critical problems during emergency situations in which operators could be manning the LCSs for extended periods.

- The existence of these human factors deficiencies at the safety-significant LCSs increases the potential for operator errors that could be detrimental to plant and public safety.

2.1.3 Application of NUREG-0700 to LCSs

Much of the material in NUREG-0700 could be applied to local control stations (refer to Section 5.1.1 of this report for details). If NUREG-0700 were used to evaluate local control stations, many of the HFE deficiencies that were found could be avoided, although the methodology described by NUREG-0700 is probably on a scale larger than that necessary for local control stations. For application to local control stations, NUREG-0700 is clearly deficient in two areas. First, the document does not adequately address the human factors design criteria for manually controlled valves. Second, it does not address the design requirements of work stations that are subject to extreme environmental conditions. These considerations have been addressed in other human factors references, among them a military standard (MIL-STD-1472C).

2.1.4 Correcting Human Factors Design Deficiencies in Existing LCSs

In future power plants the generic problem of human factors design deficiencies in LCSs could be solved by preventing the deficiencies at the outset. That is, good human factors design of LCSs would logically result from a larger plant-wide involvement of human factors from the earliest stages of plant design. This is a sensible, long-term view.

The short-term view is that human factors deficiencies in existing plants should be corrected when those deficiencies can lead to operator errors that could threaten plant and public safety. This study suggests that plant operating safety could be improved if the nuclear industry would incorporate human factors engineering improvements to the most important safety-related local control stations in existing plants.

There are some relatively inexpensive, "quick" fixes that the industry could make to their local control stations. These fixes could eliminate many (but certainly not all) of the likely sources of operator error resulting from human factors deficiencies of the sort we found at local control stations. These LCS improvements that could reduce operator errors are detailed in Section 6.1.

2.1.5 Problems in the Future

The processes of a nuclear power plant are numerous, and the control systems can be complex. As computer technologies are refined, it is likely that these control systems will become more and more automated. As a result, the operator's job during routine operations will likely become simpler.

The human factors problem with this situation is that the role of the operator is changing from active interaction with system functions to passive monitoring. The operator's job is then significantly different. The operator may need fewer skills and less training for routine operations. Yet during emergencies the operator may still be required to understand and control key functions in complex systems. The key human factors questions in this situation are -- How much control should be automated and how much allocated to the operator? How much control can be given to the machine before the operator becomes so far removed from the process that he cannot respond properly to mitigate an unexpected event? The challenge for human factors engineers and the nuclear power industry is to find the optimal relationship between automated and operator-controlled systems. Section 6.3 contains a more detailed discussion of this problem area relative to future local control stations.

2.2 RECOMMENDATIONS

Several simple modifications to control panels and workspaces can significantly reduce the probability that human errors will occur in the operation of local control stations. These modifications (described in detail in Section 6.1 of this document) should be based on the guidance provided in NUREG-0700 and in similar documents that cover areas where NUREG-0700 is thought to be deficient (see Section 5.2). These modifications are summarized in the steps below. It is essential that step 1, a preliminary analysis of plant jobs and systems, be conducted so that all safety-related LCSs in a specific plant can be identified for study. The subsequent steps can then be taken to improve the safety-related LCSs.

1. Safety systems and emergency procedures at each plant should be analyzed to determine which local control stations are safety-related.

2. Basic workstation design requirements should be identified by analyzing the operator's job at each safety-related LCS to be sure that critical tasks can be performed under anticipated emergency conditions with the expected staff.

3. Using the job analysis results as a guide, workspace design should be improved to facilitate safe, efficient LCS operation (for example: provide increased laydown area for procedures manuals).

4. Control panels should be improved to enhance LCS usability. Improvements might include upgrading labels, mimic lines, and control/display operation stereotypes to conform with the guidance in NUREG-0700.

5. Procedures and hardware should be appropriately modified to ensure the effectiveness of communication between each safety-related LCS and its anticipated control point(s).

6. A complete set of applicable operating procedures should be permanently located at each LCS within easy reach of the operator's

position. Where possible and appropriate, job performance aids (such as graphs and check lists) should be prominently displayed.

7. When adverse environmental conditions at the local control station can affect operator performance, all reasonable steps should be taken to mitigate the adverse conditions. Such measures might include properly aiming emergency lights, installing noise blocking barriers around communications workstations, or adding fans or space heaters.

8. Maintenance and housekeeping should be performed to bring the local control stations up to design standards (for example: replace missing labels, clean up dirty displays). Preventive maintenance procedures should be implemented to keep LCSs up to those standards.

3.0 REVIEW OF EXISTING DATA

This section summarizes the results and conclusions of PNL's review of existing studies of local control stations. The purpose of this review was to establish a knowledge base that could support the next project objective of actually visiting a representative group of plants to sample current industry practice.

This review had three main goals:

1. to identify which local control stations or other interfaces are involved in significant safety actions (Section 3.2)
2. to identify transient and accident scenarios that may affect environmental conditions at local control stations (Section 3.3)
3. to determine what human factors deficiencies were known to exist in the design of those interfaces (Section 3.4).

3.1 SUMMARY OF THE REVIEW RESULTS

The data review describes information obtained from a variety of different resources. In most cases, the data found did not apply directly to problems involving local control stations or auxiliary operators. Instead, we had to synthesize the data available to produce applicable conclusions.

The review did, however, lay a foundation upon which we could base our interviews for the Survey of Local Control Stations at Several Power Plants, Section 4.0.

The detailed conclusions of the review are presented in Subsections 3.1.2, 3.2, and 3.3.2. The most important conclusions are these:

- A definitive list of safety-significant local control stations cannot be specified because power plants vary: they have different control stations, and the safety significance of the control stations differs from plant to plant.
- Local control stations that have safety significance may generally be defined as: 1) those LCSs that will be manned when the control room is evacuated, 2) those required to monitor and control postaccident containment H_2 levels or routine plant radiation releases, or 3) those that may affect reactor integrity, shutdown, and accident mitigation.
- In most cases, the domain of safety-related LCS would include remote shutdown, remote reactor scram, diesel generator, vital

electrical systems (switchgear), emergency coolant injection, containment H_2 sampling, and radwaste monitoring and control.

- Twenty-eight events and malfunctions encompass expected transient and accident scenarios; some of these events may affect environmental conditions at LCSs. These events and malfunctions are listed in Appendix C.

- Although some information in NRC and EPRI reports was generally applicable to control stations, we found no human factors data related specifically to local control stations. Two primary sources of power plant data (licensee event reports and INPO plant evaluations) proved to be too general for specific analysis of the human factors design deficiencies of LCSs in this project. Most of the data found in this review could be used only as background for the later survey of local control stations.

3.2 IDENTIFICATION OF LOCAL CONTROL STATIONS OR INTERFACES INVOLVED IN SIGNIFICANT SAFETY ACTIONS

To identify the LCSs or interfaces that are involved in significant safety actions, it was necessary to establish definitions for the following terms:

- significant safety actions
- systems involved in significant safety actions
- local control stations or interfaces
- LCSs or interfaces that are important to those systems involved in significant safety actions.

Each of the following sources of information was examined to help define these terms.

3.2.1 Sources of Information

The sources of information included NRC regulations, reactor systems manuals developed by the NRC, discussions with licensing examiners at PNL, and discussions with personnel at an operating PWR. Each source is discussed in detail below.

3.2.1.1 NRC Regulatory Documents and Systems Manuals

The reviewed NRC materials were 10 CFR Chapter 1 - Nuclear Regulatory Commission, the NRC Regulatory Guides, and BWR and PWR Systems Manuals produced by the NRC Inspection and Enforcement (I&E) Training Center.

No section or statement in 10 CFR 1 explicitly states what the safety-related systems are or what systems are involved in significant safety actions. However, 10 CFR 50, Appendix A, Criterion 2 characterizes systems important to safety as those that are to be designed to withstand the effects of natural phenomena. More specifically, 10 CFR 100, Appendix A characterizes these systems as those necessary to assure a) the integrity of the reactor coolant pressure boundary, b) the capability to shut down the reactor and maintain it in a safe condition, and c) the capability to prevent or mitigate the consequences of accidents that might result in offsite exposure. Some of these accidents are listed in 10 CFR 100, which indicates that these systems are to be designed to withstand the Safe Shutdown Earthquake (SSE).

Regulatory Guide 1.29, "Seismic Design Classification," revealed more detail, characterizing 18 safety system functions that required design for the SSE (these functions are listed here in Appendix A). However, these functions are generic; that is, the guide lists no specific plant systems to provide these functions.

The BWR Systems Manual defines about 36 systems as safety related. Some of these are further categorized functionally as being either an engineered safety system, a safe shutdown system, or an engineered safety feature. The BWR Systems Manual defines significant safety actions as those actions of safety systems that are essential to avoiding specific conditions considered to be of safety significance. Such conditions are those most directly related to the limits on the integrity of the radioactive material barriers and the release of radioactive material. Significant safety actions include:

- reactor scram
- emergency core cooling
- reactor shutdown from outside the control room.

These NRC documents do not explicitly address local control stations and mention LCS functions in only a few instances. Criterion 19 of 10 CFR 50, Appendix A, does require appropriate locations outside the control room for conducting both prompt hot shutdown and subsequent cold shutdowns. Also, the BWR Systems Manual makes passing reference to a radwaste (radiation waste) control panel.

3.2.1.2 Operator Licensing Examiners

Two knowledgeable examiners from the NRC's reactor operator examination program were asked to define local control stations and to identify those which would have safety significance. Both examiners said that "local" meant outside the control room and that anything from a single local manual control, such as a valve, to a collection of controls and instruments could be considered a local control station. They concluded that the definition of which LCSs are safety significant is probably plant specific. In view of these responses, one way to determine the safety significance of LCSs (prior to plant visits) would be to consider 1) which local stations must be manned during a control room evacuation and 2) which local stations must be manned either routinely or after an accident.

Station functions manned during a control room evacuation are:

- remote reactor scram
- remote shutdown
- diesel generator control
- vital electrical systems
- emergency safeguards system status.

About 15 separate systems could be covered by these five panel categories, although not all plants have every kind of panel. Included among the stations that are more routinely manned (i.e., even when the control room is operational) are the radwaste disposal and treatment panels and the postaccident containment H_2 analysis panels.

The two categories of station control functions (those manned routinely and those manned during a control room evaucation) encompass such "significant safety actions" as reactor scram, core cooling, and control of radioactive releases. These could be considered the most significant or primary functions. However, one examiner noted that there are secondary functions, such as emergency equipment cooling, that support the primary functions. There may also be systems required only because their failure to function could degrade the functions of the primary- and secondary-level systems (see item 18 in Appendix A, Safety System Functions). A good example of this type of problem occurred on May 27, 1983 at Calvert Cliffs Unit 1 when both emergency core cooling system (ECCS) room coolers were out of service for 22 hours. According to IE Information Notice 83-56, "Operability of Required Equipment," certain accident conditions could have required the coolers to support long-term operation of engineered safety feature pumps. The coolers had been removed from service for routine maintenance, but following the equipment outage, calculations performed by the licensee indicated that, because of temperature limitations, the safety-related equipment located in the two ECCS rooms could not have performed their required functions if an accident had occurred. The equipment included all high-pressure safety injection, low-pressure safety injection, and containment spray pumps.

3.2.1.3 Visit to an Operating Nuclear Power Plant

Before the principal plant visits of this project, we met with personnel at an operating PWR to discuss and see local control stations considered to have safety significance. Conversations with the plant personnel centered on items from a list of "Safety Systems Functions" and from an accompanying analysis form (Appendices A and B, respectively). These preliminary draft forms were based on the analysis of safety-related local control stations described in Sections 3.2.1.1 and 3.2.1.2 of this report. The purpose of the plant visit was to obtain an industry assessment of the results of the analysis to date and to obtain firsthand information about the human factors problems of local control stations. These problems could then be more accurately addressed during the interviews and measurements being planned for later plant visits.

The plant personnel defined a "control station" as a place from which someone (a central person) directs multiple functions; the local person(s) who are thus directed are responsible for actually manipulating switches, valves, or other controls, or for monitoring remotely located displays. The "control room" is the main control station, that is, the one from which all operations of the reactor are directed. A "local control station," then, they defined as a control station outside of the main control room from which someone may direct multiple functions. This definition necessarily limits the class of local control stations to a relatively few, major locations throughout the plant (for example, the remote shutdown and radwaste panels). However, three of the systems they showed us (the switchgear room panels, diesel generator panels, and remote shutdown panel) were manually operated stations from which no other functions were directed.

The PWR plant personnel also expressed the view that, with few exceptions, only when the control room must be evacuated certain LCSs attain a safety significance. Otherwise, under all emergency conditions, including a Loss-of-Coolant Accident (LOCA), systems functions are controlled or restored from the control room, although some sampling functions are performed locally. If the control room at the PWR must be evacuated for some reason, the reactor is first manually scrammed, and the following LCSs are manned:

- remote shutdown panel
- diesel generator panel(s)
- switchgear panels

- charging pump/flow panel
- radiation waste (radwaste) panel
- containment H_2 sampling panel.

The first three of the LCSs listed above were visited to obtain a general human factors perspective that could aid in planning the plant visits described in Section 4.0. The primary environmental problems observed were related to high noise levels and, to a lesser extent, adequacy of lighting. It was apparent that communication systems also needed to be evaluated in terms of both location relative to the LCS and effectiveness in the LCS environment.

Many of the older plants (i.e., those in operation before the early 1970s) do not have remote shutdown panels, per se. In these plants, important parameters are monitored at local instrumentation racks, and important systems are operated locally. As an example, when the control room at the Oyster Creek power plant (a BWR-2 model) must be evacuated, the following six parameters and systems are locally monitored and verified to ensure reactor shutdown:

1. Reactor water level - monitored on RK01 or RK02
2. Reactor pressure - monitored on RK01, RK02 or at 23-ft 6-in. elevation in reactor building near CRD pressure/flow control equipment
3. Drywell pressure, temperature, and humidity at RD03
4. Reactor water temperature at RK05 inlet to cleanup system
5. Reactor scram may be insured by shutting air header to scram valves and venting pilot valve air header.
6. Verify Emergency Condenser operation locally and manually, valve in local water level indication and add water to the condenser as necessary

It should also be noted that even when plants have "remote shutdown panels," the systems contained on these panels are not necessarily the same from plant to plant.

To summarize, our interviews and observations during the pilot visit to an operating nuclear power plant provided valuable insights about the problems of defining safety-significant LCS and the nature of LCS human factors problems. Plant personnel provided us with a definition of LCSs having safety significance that was similar to that of the primary LCSs of the PNL examiners, except that the plant personnnel restricted the time that an LCS attains safety significance to only when the control room must be evacuated.

3.2.2 Conclusions - Local Control Stations Having Safety Significance

While NRC regulatory documents do not specifically define LCSs or LCSs having safety significance, some conclusions can be drawn based on the combined information from all the sources:

- An LCS is a control station (outside of the control room) where direction of functions and/or direct manipulation of controls occur.

- LCSs having safety significance are 1) those that will be manned when the control room is evacuated, 2) those required to monitor and control plant postaccident containment H_2 levels or routine plant radiation releases, or 3) those that may affect reactor integrity, shutdown, and accident mitigation.

- Often there are secondary systems and components that are necessary to support the LCS functions above. LCSs that control these secondary systems have safety significance to the extent that their failure to function could degrade the higher-level functions.

- Although personnel at one power plant consider certain LCSs to have safety significance only upon evacuation of the control room, the need of these LCSs to be operable in that contingency should mark them as having safety significance.

- The particular LCSs having safety significance will vary from plant to plant. In most cases, the domain of safety-related LCSs would include (but not be limited to)

  - remote shutdown
  - remote reactor scram
  - diesel generator
  - vital electrical systems (switchgear)
  - emergency coolant injection
  - containment H_2 sampling
  - radwaste monitoring and control.

Some plants are not equipped with a remote shutdown panel.

3.3 IDENTIFICATION OF TRANSIENT AND ACCIDENT SCENARIOS

The identification of transient and accident scenarios was undertaken to help determine if hostile environmental conditions (e.g., high-noise levels, poor visibility, radioactivity, and extreme temperature) may be present when specific LCSs are involved in significant safety actions. A recent report that was prepared by PNL for NRC was reviewed to obtain a listing of relevant abnormal and emergency events.

Appendix C lists 28 events and malfunctions, most of which are further divided into event initiators. These events and malfunctions encompass the expected transient and accident scenarios for nuclear reactors. The listing of transients and accidents was used as background in preparing for later plant visits and for developing interview guide items that would address the environmental conditions to be anticipated at relevant LCSs.

3.4 REVIEW OF HUMAN FACTORS DATA RELATED TO LOCAL CONTROL STATIONS

One of the key goals of this study was to identify the human factors deficiencies in plant interfaces that involve significant safety actions. This identification (Section 4.2.2) is part of the second project task, which was to sample current industry practices through a series of plant visits. A review of LCS human factors data was undertaken to improve the quality of those visits by providing background information for use in interpreting responses to questions posed in an interview guide. The interview guide prepared for the plant visits is described in Section 4.1.

3.4.1 Sources of Information and Results

The sources of the human factors data related to local control stations included the Institute of Nuclear Power Operations, Licensee Event Reports (LERs), the Electric Power Research Institute, and NRC contractor reports.

3.4.1.1 Institute of Nuclear Power Operations (INPO) Plant Evaluations

Plant evaluations conducted by INPO were examined to ascertain what evaluation findings, if any, pertained to the operational safety or human factors design characteristics of local control stations.

One evaluation item in the "Performance Objectives and Criteria for Plant Evaluations" (INPO, 1982) apparently relates to local control stations. This item is labeled variously OP.6, OP.2-1, and OP.306, Rev. 1, "Operations Facilities and Equipment." Criterion D of this section states: "Physical characteristics and conditions, environment, and maintenance of plant control stations support safe and reliable operation." The entries of this general section and the results are reported below.

The "Operations Facilities and Equipment" sections of INPO evaluations for nineteen different plants were examined. Of these, only eight had entries in the targeted section, "Operation Facilities and Equipment." Two of the eight entries were not related to local control stations.

However, the other six plant evaluations did discuss several problems relating to local control stations. Some of these were housekeeping and minor maintenance problems: scaffolding that blocked access to station controls, dirty panels, burned out bulbs on local valve indicators, and instruments reading off the scale.

Two other evaluation entries referred to communications problems. One plant evaluation stated that even though the plant paging system employed flashing lights in high-noise areas to get operator attention, there were some areas in the plant where the page could not be heard and the flashing light could not be seen. The second communication-related problem was that in many areas of one plant, the paging system could be heard but not understood, apparently because poor-quality equipment was used.

The INPO plant evaluations provide general environmental information but have limited value in supporting the detailed analysis of human factors attributes of LCSs because these features are not specific evaluation items. The INPO evaluation criteria were designed for a different purpose than our very detailed analysis. Consequently, we found the INPO data to be too general to be of much use in our study. As a result of this assessment, we conducted no further analysis of INPO plant evaluations.

3.4.1.2 INPO and Department of Labor Job/Task Analysis

INPO is now engaged in a project to analyze all the tasks associated with 10 different operational and maintenance positions within a nuclear power plant. One of these positions is that of auxiliary operator (AO). Since the auxiliary operator is nominally the main user of local control stations throughout the plant (except when the control room is evacuated), a task analysis of this position could prove useful in studying local control stations. Unfortunately, the AO task analysis has not yet been completed by INPO and therefore is not yet available.

The INPO job task analysis is being conducted for the express purpose of developing recommendations and a supporting data base that would allow the utilities to systematically design and develop a variety of performance-based t:_ining programs for selected operational and maintenance jobs. It does nevertheless provide extensive information about the conditions under which tasks are performed, the nature of the action itself, the procedures and equipment used, and the personnel with whom the worker interacts during task performance. If it were available, all of this information could prove useful in developing an understanding of how local control stations function within the plant system as a whole.

Since the INPO job task analysis was not available, we decided to obtain general AO task analysis information during the course of our plant visits reported in Section 4.0. Even if INPO had provided a complete task analysis form, it would still have been necessary to relate that task information to LCSs having safety significance. Our plan was to obtain detailed task information from a person who was knowledgeable about the operation of each of the LCSs that we would actually be examining. It should be emphasized that this planned task analysis was not intended to approach the INPO effort in breadth and detail, nor was it planned to result in a separate task analysis document. Instead, its focus was only on the man/machine interface between the AO and each LCS and on the communications interface between the AO and the control room. Its only purpose was to support the human factors evaluation of those particular LCSs.

We subsequently obtained a set of Job Analysis Schedules from the U.S. Department of Labor's Occupational Analysis Field Center in Raleigh, North Carolina. These schedules, described the jobs of Auxiliary Control Operator, Auxiliary Equipment Operator, and Plant Equipment Operator. One of these schedules, that for Auxiliary Control Operator, is presented in Appendix D. Like the INPO task analyses, these job analyses were prepared for a very different purpose than our study. Nevertheless, because the schedules are closely keyed to benchmarks found in the Handbook for Analyzing Jobs (U.S. Dept. of Labor, 1972), they did provide useful background information for our data collection effort.

3.4.1.3 Licensee Event Reports (LERs)

Licensee Event Reports are probably the most commonly used source of information about plant performance. They are reports produced by utilities as required in Regulatory Guide 1.6, "Reporting and Operating Information, Appendix A--Technical Specifications," whenever violations of plant technical specifications or other events of potential public interest occur. The reports fall into two categories: first, those requiring immediate reporting because they involve plant shutdown or nonoperational safety-related systems, and second, those requiring a report within 30 days because they involve degraded operation of a system for which a substitute, redundant system is available. LERs may also be prepared when a plant event involves some kind of property damage or release of radioactivity.

The primary sources of LER data for evaluating human factors related to LCSs are individual items within the LERs. These items include six codes that indicate the cause of the event, a subcode, a narrative "event description and probable consequences," and a narrative "cause description and corrective action." The single cause code most applicable to the purpose of analyzing human factors features of LCSs is "personnel error," although some information might be obtainable from other categories. For events occurring between June 1, 1981 and December 17, 1982, we found 24 LERs of LCS-related events. All 24 LERs recorded "personnel error" as a cause code. Few of these LERs yielded information about the underlying human factors deficiencies of the LCSs. Unfortunately, a major deficiency of using the LER system for our purposes is that the LERs provide general characterizations of an event rather than specific human factors information.

In a survey of potential performance indicators for assessing NRC licensees, McLaughlin (1983, p. 15) identified five sources of variations in the frequency of LER coming from a particular plant. These are summarized below.

1. Technical specifications and license provisions for old plants are more lenient than those for new plants. These variations cause differences in the reporting requirements that relate to violations of technical specifications.

2. "There may be a tendency at some facilities to report some events more readily than others. This tendency can also change with time." These variations in reporting practices result from the fact that the regulations leave room for interpretation. Since the licensee event report process involves the utility reporting on itself, some companies may issue LERs for trivial problems so they appear to be in compliance while not reporting more serious problems.

3. "The occurrence of an event may affect the probability of a future event. The repair of a component may increase the likelihood of an associated event. On the other hand, an ineffective action following an event may result in repeated occurrence."

4. "The mode of operation (e.g., on-line or in a shutdown) influences the susceptibility of the systems of LER events. The amount of downtime may affect the frequency of LERs."

5. "When doing comparisons between units at the same facility, LERs that involve generic plant systems or components common to all

units are reported by the NRC under the docket number of the first unit."

McLaughlin concludes that analysis of LER data can be of value if a number of controls are applied to the selection of cases and if only general results are sought. Unfortunately, human factors analysis of local control stations demands very specific data about causal relationships between the operator and his control panel.

We did, nevertheless, conduct a general analysis of LER data to ascertain if there were any human factors deficiencies we should particularly look for during our plant visits.

Our examination of LERS for events occurring between June 1, 1981 and December 17, 1982 revealed 24 LERS in which personnel errors affected the performance of safety-related systems. Seventeen of these LERs involved misalignment of valves, and seven involved misalignment of breakers/control switches. Appendix E lists the 24 events.

The events involving valves consisted of the following:

- valve misalignment that resulted in the isolation of indicators, transmitters, or switches--for pressure, flow, or level - 10 LERs

- equalizing valves left open so that system parameters became unknown or safety system functions became inoperable - 3 LERs

- offgas system sample valves misaligned so that radioactivity discharge from the plant was unknown - 3 LERs

- instrument line test tee cap missing so that containment integrity was violated - 1 LER

The events involving breakers/control switches consisted of the following:

- breakers tripped open, leading to inoperability, spurious signals, unknown states of safety systems, or reactor trips - 6 LERS

- three containment air radiation monitors inoperable because control switches were left in "test" position - 1 LER

Our analysis of these LERs reinforced our belief, however, that they are not useful for the purpose of analyzing specific human factors design problems in local control stations because they provide no clear information about the human factors design deficiencies that underlie the events.

On the other hand, LERs can, as indicated above, have some limited capacity to identify global human factors problems associated with specifically targeted local control stations. They might also confirm the results of the analyses already performed to identify critical LCSs or to identify events not already listed as safety-related. If this information became important, a general survey of LER data could be conducted using the computerized RECON data base compiled by the Oak Ridge National Laboratory. Such a detailed survey was not conducted as part of this study but may constitute a logical follow-on project that builds upon the results of the plant survey presented in Section 4.0.

3.4.1.4 Electric Power Research Institute (EPRI) Reports

Reports produced by EPRI were reviewed to obtain general human factors information that could apply to this project. None of the reviewed EPRI documents pertain specifically to local control stations, although several have sections that were helpful in preparing the interview guide for the plant visits and in subsequently evaluating the LCSs. These documents and their contributions are listed below.

- EPRI NP-1918-SR, "Anthropometric Data Base for Power Plant Design"

  This document provides basic anthropometric information about nuclear power plant workers. The information can be used in the evaluation of the physical layout of local control stations.

- EPRI CS-1760, "Assessment of the Use of Human Factors in the Design of Fossil-Fired Steam Generating Systems"

  This document contains a detailed human factors check list for control panels and relates the check list items to human error probabilities.

- EPRI NP-1118 "Human Factors Methods for Nuclear Control Room Design," Vols. I, II, III and IV

  This series of volumes describes existing problems common in nuclear power plant main control room panels and suggests solutions. Volume 3 is especially interesting because it describes human factors methods applied in developing and evaluating conventional, hard-wired control panels. Volume 2 is a survey of control board design practices as determined through structured interviews of panel designers.

- EPRI NP-2411, "Human Engineering Guide for Enhancing Nuclear Control Rooms"

  This document contains a useful collection of human engineering problems that may apply to some local control stations. Each problem is well documented and illustrated and includes sections on "significance" and "backfit objectives" for readers interested in upgrading their control rooms.

- EPRI draft document, "Guide of Systemmatic Evaluation of Human Factors in Nuclear Power Plant Development"

  This document is now being prepared by EPRI and portions of it were used in draft form in support of this project. Some of the general human factors information in this document is applicable to the evaluation of local control stations.

3.4.1.5 Nuclear Regulatory Commission (NRC) Contractor Reports

Three major NRC contractor reports contained information directly applicable to the goals of this data review. These NRC contractor reports (listed below) contain information that is central to the task of evaluating safety-related interfaces. This information was used in devising the interview guide used to collect information during the plant visits described in Section 4.0.

- NUREG-0700, "Guidelines for Control Room Design Review"

  This document is the primary source for the human factors evaluation of control stations and safety-related interfaces. However, because it is designed for control room design reviews, it may not be ideal for use in assessing problems in the harsh environmental conditions and lower-level technologies commonly found at some LCSs in the plant. (One purpose of the present study is to assess the adequacy of applying NUREG-0700 to LCSs. Refer to Section 5.0.) The document provides useful procedures and forms for measuring local environmental conditions and conducting a systematic control room review.

- NUREG/CR-2623, "The Allocation of Functions in Man-Machine Systems: A Perspective and Literature Review"

  This report describes basic issues in allocating functions between humans and machines. These ideas can be applied to the human factors assessment of local control station functions once a very detailed, applicable task analysis is developed. Much of the report covers sophisticated computer systems that can automatically allocate functions, but parts of the report describe the allocation of functions in at least partially automated systems, such as those found at radioactive waste control stations.

- NUREG/CR-1278, "Handbook of Human Reliability Analysis With Emphasis on Nuclear Power Plant Applications"

This is the basic text on assessing the probability of human error. For the purposes of this project, the section on performance shaping factors proved useful in assessing possible problem areas that should be on the interview guide developed and used in the plant visits described in Section 4.0.

3.4.2 Conclusions of the Review of Human Factors Data

We found no human factors data related specifically to local control stations or safety-related man-machine interfaces outside of the main control room. However, several EPRI and NRC reports did present information about human factors design problems observed in nuclear power plant control rooms. This information is applicable to interfaces throughout the plant. On the other hand, plant evaluations conducted by INPO add little, for our purposes, to the generally available information about human factors problems, so analysis of the INPO plant evaluations was not pursued further. Since the INPO task analysis information was not available in time for use by this project, general job analysis information was obtained from the U.S. Department of Labor, and interviews of LCS operators about their tasks were conducted during the plant visits. Analysis of LER data is useful in identifying broad areas of human factors concern and aids in determining which plant interfaces have the most problems. However, these data do not indicate specific human factors design problems or possible solutions but only support actual onsite investigations that can determine underlying causes and appropriate solutions.

4.0 SURVEY AND HFE ANALYSIS OF LOCAL CONTROL STATIONS AT SEVERAL POWER PLANTS

The planned activities of this task were to visit a representative sample of nuclear power plants and to examine local control stations within the plants. The purpose of these activities was to identify deficiencies in the human factors engineering (HFE) of local control stations if such deficiencies existed. During the plant visits, these local control stations were studied:

1) remote shutdown (auxiliary feedwater) panel

2) radwaste control panel

3) emergency diesel generator panel

4) containment hydrogen recombiner control panel

5) manually operated makeup control switch for the high-pressure injection system

6) manually operated valve for the main feedwater line

7) manually operated control valve for the primary makeup water

No plant contained all of these stations, and only a few stations were surveyed at each plant.

The following discussions present the methods of the survey and the survey results and analysis.

4.1 METHODS OF THE SURVEY

The selection of nuclear power plants was planned to include two representative plants (one modern, one older) for each of the reactor vendors: General Electric, Babcock and Wilcox, Combustion Engineering, and Westinghouse. We contacted a representative group of plants but were turned down by some utilities because several plants were too busy to support our effort (because of refueling outages or NRC-related work) during the period when plant visits were planned; others were not receptive to a visit in any case. The final selection of four plants included one General Electric BWR, one Babcock and Wilcox PWR, and two Westinghouse PWRs. Table 4.1 shows the selection of plants that were visited early in 1983 and the specific local control stations examined at each plant.

A two-person team from PNL spent one day at each plant. The initial discussion during each visit determined the selection of local control stations to be studied at that particular plant. This selection was made based on the definition of safety-significant LCSs described in Section 3.0. Utility personnel were asked to identify those local control stations that would be manned if the main control room had to be evacuated. Once these were identified, utility personnel were asked to suggest which of this subset of stations they considered to have troublesome features based on our discussion. The PNL team then selected two or three target local control stations from those suggested.

TABLE 4.1. Local Control Stations Examined at the Visited Plants

Plant Type	Vendor	Local Control Stations Examined
BWR	General Electric	Radwaste control panel Emergency diesel generator
PWR	Babcock & Wilcox	Remote shutdown panel Manually operated makeup control valve for high-pressure injection system Injection-side isolation valve for emergency feedwater system
PWR	Westinghouse	Remote shutdown panel Manually operated valve for main feedwater line Hydrogen recombiner panel
PWR	Westinghouse	Remote shutdown panel Radwaste control panel Manually operated control valve for primary makeup water

4.1.1 Interviews

To assess any HFE design deficiencies at each local control station, interviews were conducted using a previously prepared interview guide. This interview guide was derived primarily from two sources: Appendix C, "Control Room Operating Personnel Interview Protocol" from NUREG-0700; and our pilot investigation of an operating PWR power plant described in Section 3.2.1.3. In some cases, NUREG-0700 questions were deleted, added, or modified slightly to make the guide better suited to the evaluation of local control stations rather than main control rooms. Section C1, "Guidelines for Operator Interviews" from NUREG-0700 was used as a guide for actually conducting the interviews, although it is important to note that not all questions applied to every type of local control station. The interviewer used his judgment to decide which questions to ask relative to each control station. Among the topics on the interview guide were:

- Operator familiarity with the local control station
- Panel design
- Annunciator warning system
- Workspace layout and environment
- Communications
- Operator comfort.

Appendix F is a copy of a blank interview guide. As mentioned earlier, all interview topics were not relevant to each local control station, so only a subset of questions were asked at any particular panel or control.

While the interviewer covered these topics with the utility personnel, the second team member measured environmental conditions at the station including lighting, noise level, air flow, temperature, and humidity. The check list for the environmental measurements is presented in Appendix G. This check list and all the measurement procedures used (including photography) were adapted as directly as possible from NUREG-0700.

4.1.2 Photography

Appendix D, "Photography Guidelines" of NUREG-0700 served as a guide for taking pictures of each local control station. This photography was used to record panel design information for later human factors assessment and analysis. Some of the photographic mosaics made of the control panels appear as illustrations in the Survey Results and Analysis, Section 4.2. We were not able to construct perfectly accurate panel-by-panel mosaics because of our particular need to work quickly and because obstructions sometimes made it impossible to set up a camera for precisely overlapping photographs. We were, nevertheless, successful in obtaining adequate (for our purposes) photographs of every local control station we visited.

4.1.3 Environmental Measurements

The sound survey we conducted closely followed Section E1, "Sound Survey Procedures" from NUREG-0700. All sound measurements were made using a General Radio Model 1933 Precision Sound Meter Analyzer. The sound level meter was calibrated immediately before each plant visit by using a General Radio Model 1562-A calibrator in accordance with the recommended procedure in the user's manual.

Similarly, the lighting survey followed Section E2, "Lighting Survey Procedures," except that we were not able to obtain measurements of full dc emergency lighting from the plants. In a few instances we made estimates of the emergency lighting adequacy, particularly with respect to the direction in which the emergency lights were pointed. For light measures we used a professional photographer's light meter, that was calibrated in foot candles.

Temperature measurements were obtained by taking readings at the operator's position at each local control station using a simple manual psychrometer. The dual thermometers on this device yielded both wet and dry bulb temperatures. Relative humidity was then derived from the two temperature measures using a psychrometric chart developed by H.W. Carrier (Eshbach, 1975).

We did not, as suggested in Section E3 of NUREG-0700, set up meters in undisturbed areas and take readings every hour for 24 hours. The scope of our study did not warrant that kind of effort. Our air velocity survey, conducted along with the temperature measurements, consisted of making subjective estimates at two heights: 4 ft and 6 ft using a form similar to the "Air Velocity Survey Record" presented on page E-6 of NUREG-0700.

4.2 SURVEY RESULTS AND ANALYSIS

The interviews, photographs, and environmental measures were analyzed to establish the kinds of HFE design deficiencies present in the control stations we examined. This analysis is described in Section 4.2.2. Detailed reproductions of the interview and photographic results are not included in this report; rather, specific examples of these results are incorporated in the analysis in Section 4.2.2. The detailed measures of environmental conditions are included in Section 4.2.1, which not only presents the environmental data but also discusses some current standards for working environments.

4.2.1 Environmental Conditions

People have a substantial ability to adapt to changing environmental conditions. However, there is also a range for which optimum performance is achieved. As departure from this optimum occurs, human performance, comfort, and ultimately, health, can be affected.

Environmental factors discussed in this section include air variables (temperature, humidity, velocity), illumination and noise. Although these conditions are discussed separately here, one must be aware of interactive effects that can be detrimental to human performance. All of these conditions must be addressed to assure the safety, accuracy and efficiency of performance required at local control stations while personnel execute critical plant functions.

Each of the discussions includes a table of the environmental data gathered during the plant visits.

4.2.1.1 Air Temperature, Humidity and Velocity

Conditions of air temperature, humidity and velocity can produce environments that are stressful to personnel attempting to perform even the simplest of job requirements. Discomfort, degraded task performance, and even damage to health can result when environmental demands exceed the individual's capability to adjust, or in this case, regulate body temperature.

This section discusses the data collected at specific local control stations and indicates action that could improve the thermal environment. Appendix H addresses in more detail the importance of providing an optimum thermal environment to assure task completion at local control stations; body temperature regulation and external factors affecting temperature regulation are included in the discussion.

Local Control Station Data - Air Temperature, Humidity, and Velocity

Wet-bulb and dry-bulb temperatures, relative humidity, and air velocity for 10 different local control station locations are presented in Table 4.2. The air velocity data were obtained at two heights using subjective measures as explained in Section 4.1.3. Because air temperature, humidity, and velocity interact to affect body temperature regulation, it is useful to refer to an index that integrates these factors--an effective temperature (ET) scale. Figure 4.1 shows an effective temperature scale that was developed under the sponsorship of the American Society of Heating, Refrigeration, and Air Conditioning Engineers (McCormick, 1976). The scale indicates thermal zones of relative comfort and discomfort. The intersection of the dry-bulb and wet-bulb temperatures give the relative humidity and also the corresponding effective temperature as desired. Our local control station data (the open circles) are plotted onto the effective temperature scale.

The data obtained from 10 different local control stations do not, for the most part, fall within the narrow comfort zone outlined in Figure

TABLE 4.2. Local Control Station Air Temperature, Humidity, and Velocity Data

ID #	Local Control Stations	Temperature (°C,°F) Dry Bulb		Wet Bulb		Humidity	Air Velocity 4-ft Height	6-ft Height
	Multi-Function Panel							
2-1	Remote Shutdown	32.9	91.2	25	77	53	slight	slight
3-1	Remote Shutdown	22.8	73.0	18.5	65.3	69	moderate	moderate
4-2	Remote Shutdown	23.5	74.3	17	62.6	51	slight	slight
1-2	Radwaste Control	29	84.2	22.5	72.5	56	slight	slight
4-1	Radwaste Control	21.5	70.7	16.5	61.7	60	slight	slight
3-2	Hydrogen Recombiner	23.1	73.6	17	62.6	53	--	--
1-1	Deisel Generator Ctrl	32	89.6	23	73.4	46	none	none
	Diesel Engine Control	33.5	92.3	24	75.2	46	--	--
	Single-Function Switch							
2-2	HPI Makeup Control Valve Actuation	27.5	81.1	25.5	77.9	87	slight	slight
	Single-Function Valves							
4-3	Primary Makeup Water Control	29	84.2	22	71.6	53	slight	slight

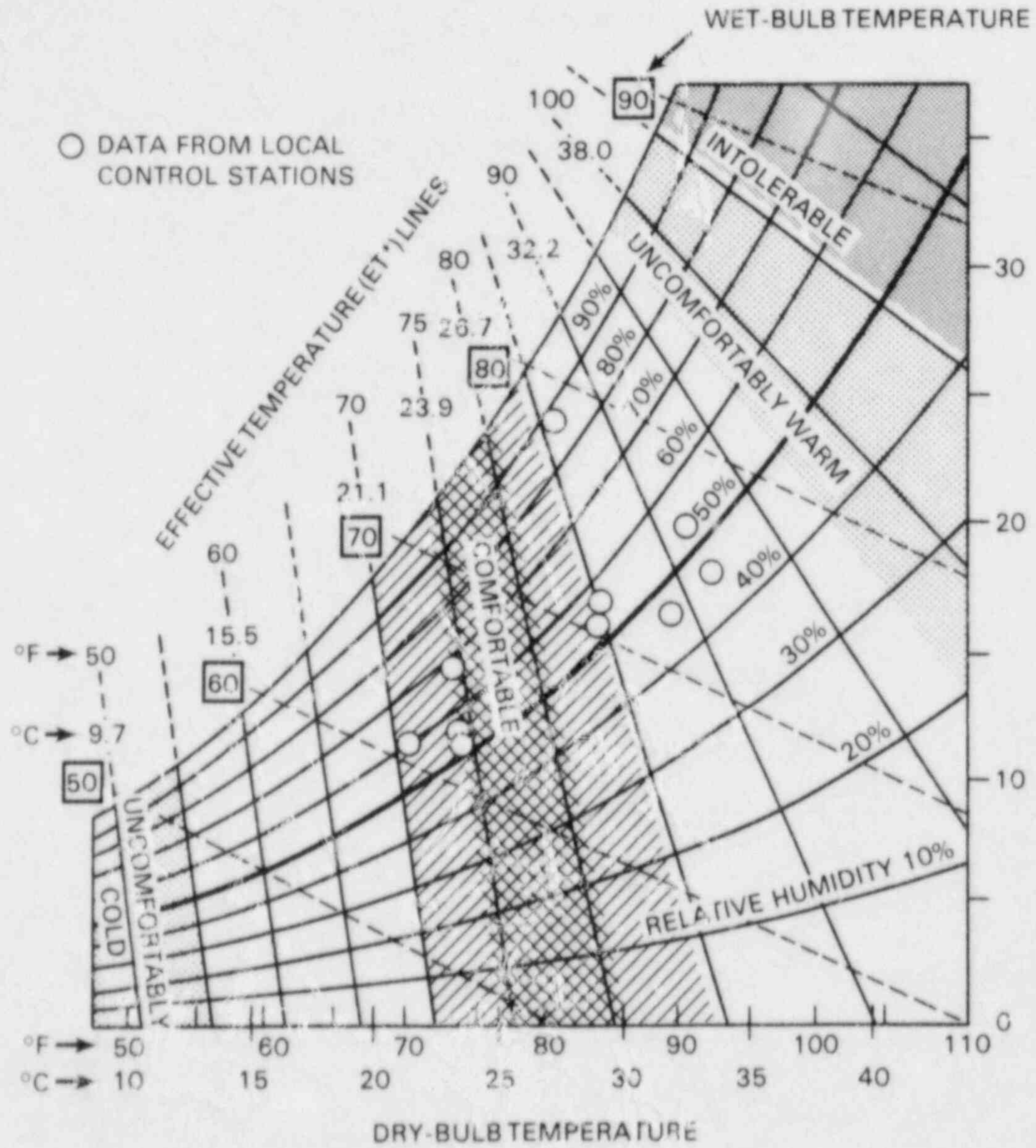


FIGURE 4.1. Effective Temperature Scale with LCS Data

4.1. However, 40% of these values fall within the slightly warm or cold zones, and all data points fall between zones considered to be uncomfortably warm or cold as defined in Figure 4.1. At first glance these results appear to be very acceptable, especially if it is considered that work would be performed at these locations infrequently. However, several additional factors should be taken into consideration. At nuclear power plant local control stations it is assumed that temperature extremes are more likely to occur at the high end of the scale than at the low end. In an emergency, radiation exposure could necessitate the use of protective garments at specific local control stations within the plant. Protective equipment can be restrictive and prevent evaporative and convective heat loss. In such situations, heat stress may increase rapidly. In addition, personnel may be required to man local control stations for 6 to 8 hours in the event of an emergency shutdown. Increasing exposure to high temperatures and humidity, and "stagnant" air may have a detrimental effect on performance as well. Figure 4.2 illustrates this principle using data obtained from 15 studies (3 sets of researchers) investigating sedentary performance (Konz, 1979). At effective temperatures above the three curves shown, some decrease in performance must be expected.

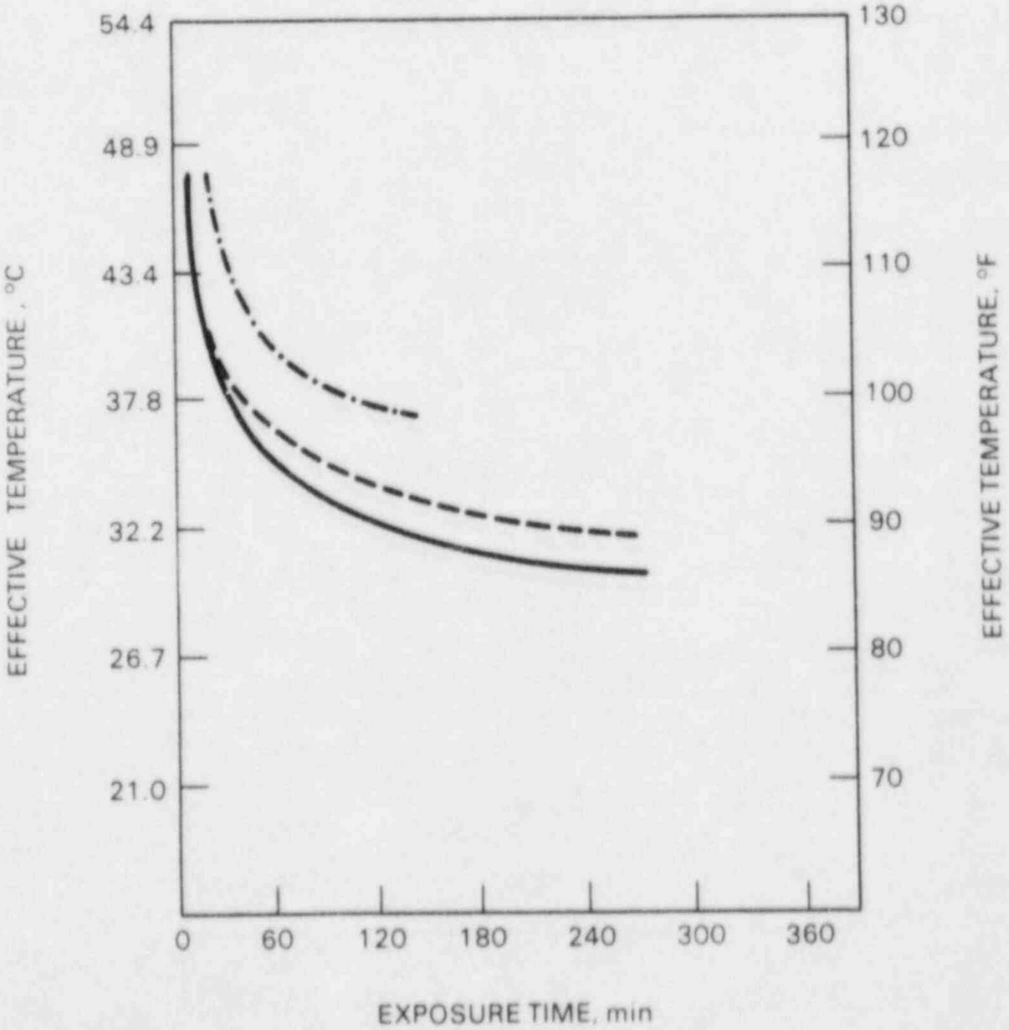


FIGURE 4.2. Upper Effective Temperature Limits for Sedentary Performance Without Degradation of Performance

Improving the Thermal Environment

While it is not feasible to set any single set of environmental conditions that could be specified as acceptable to all situations, several recommendations can be made in an attempt to reduce potential heat stress associated with local control stations. In warm-moist environments, excess water vapor can be removed through air conditioning. Insulation or shielding can be used to reduce thermal radiation present. Circulating air coupled with a decrease in air temperature can help to increase evaporation and maintain effective convective cooling. Although it may not be feasible to modify environmental conditions within the plants as a whole, it may be possible to provide an isolated environment (microclimate) for personnel at local control stations. This isolated environment could take the form of a environmental chamber which would contain the local controls or it could take the form of protective garments such as that researched by Kamon (EPRI-NP 2868).

4.2.1.2 Illumination

Illumination plays an important role in the safety and accuracy of task performance. Not only can visual performance be negatively affected by conditions of poor illumination, but the eye will attempt to compensate or adapt to given illumination conditions, which can result in an additional fatigue factor related to performance. This section discusses illumination data obtained from specific local control stations. Appendix H addresses in more detail the importance of providing adequate illumination to assure the safety and accuracy of task completion at local control stations; factors affecting illumination are presented in an effort to address total visual performance.

Local Control Station Data - Illumination

Illumination is a measure of the area density of light reaching a target or surface. Illumination data, in foot candles, is presented in Table 4.3 for 18 different locations associated with local control stations. Meter readings were taken under normal conditions and in four locations under emergency illumination conditions. The illumination data obtained from local control stations is plotted (open circles) with minimum recommended levels of illumination (NUREG-0700) in Figure 4.3. Because a large percentage of the illumination data from local control stations involved displays and controls, the minimum recommended values selected from NUREG-0700 for comparative purposes were those for auxiliary panels. Of the 18 data points available, approximately 45% of these data fell above the minimum recommended value for auxiliary panels (20 ft-c). Another 45% of the data fell below the minimum recommended values for control room emergency operating lighting. While three of these values were in phone areas, three were also at auxiliary control panels.

TABLE 4.3. Local Control Station Illumination Data

			Meter Reading (ft-c)	
ID #	Local Control Stations	Description	Normal	Emergency
	Multi-Function Panels			
2-1	Remote Shutdown	Flat on panel surface	9	--
		On sheet of paper held at 45° angle in the phone booth	3.8	--
		On sheet of paper held in light using the phone	15	--
3-1	Remote Shutdown	Surface of panel	30	--
		At the phone	4	--
4-2	Remote Shutdown	Panel face - right panel surface	38	32
		Panel face - left panel surface	32	35
1-2	Radwaste Control	Flat on panel surface	60	60
		At the phone at reading height and angle	40	40
2-2	Radwaste Control	Panel surface	7	--
4-1	Radwaste Control	Surface of a book placed on angled lower panel	75 (est)	--
		Surface of vertical panel	56 (est)	--
3-2	Hydrogen Recombiner	Panel surface	60	--
1-1	Diesel Generator	Panel surface	16	--
	Diesel Engine Ctrl	Panel surface	4	--
	Single-Function Switch			
2-3	HPI Makeup Control Valve Actuation	Surface of switch panel	3	--
	Single-Function Valve			
4-3	Primary Makeup Water	At the valve	7	--
		At the phone	9	--

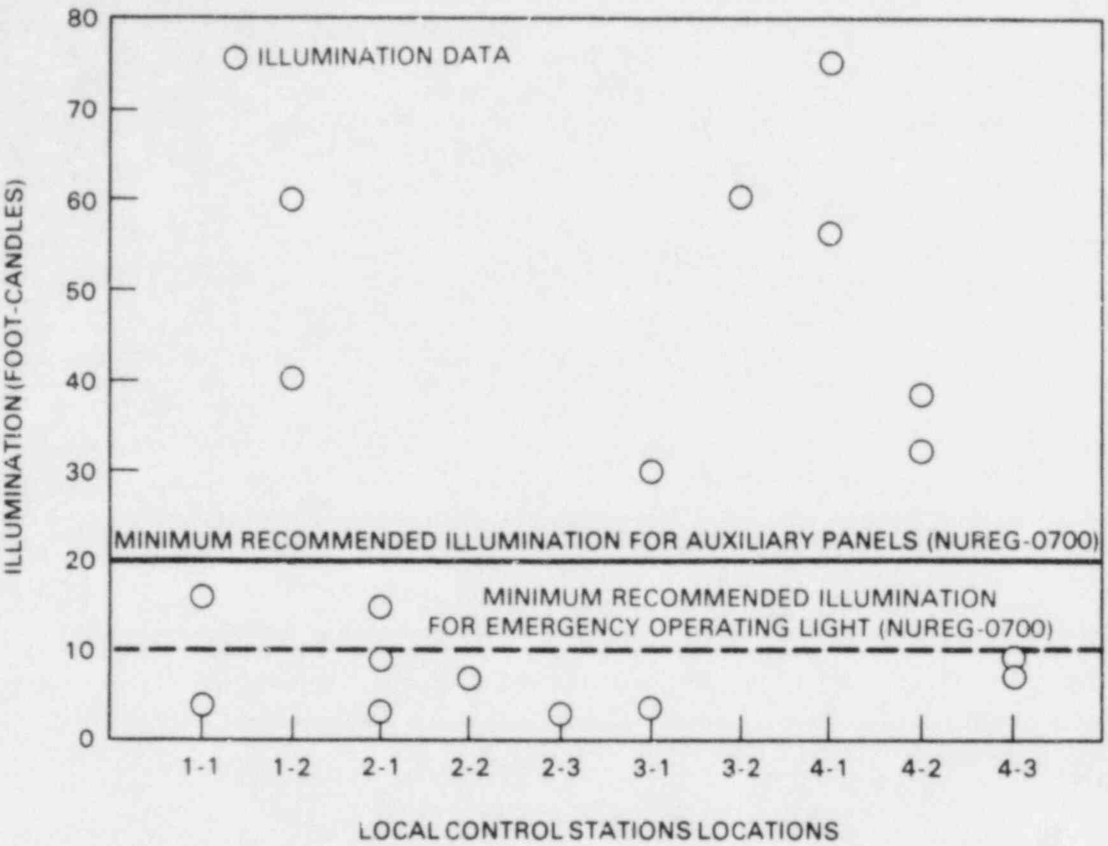


FIGURE 4.3. LCS Illumination Data Plotted with Recommended Values From NUREG-0700

In power plant areas where single switches are actuated or valves are opened or closed, one would not necessarily expect illumination levels to exceed some set emergency lighting level. However, where auxiliary controls needed for power maneuvering or system shutdown require operators to remain over long periods, adequate illumination levels should be required to prevent fatigue and potential errors. Where fixed illumination is not available, supplemental lighting should be provided.

4.2.1.3 Noise

Excessive noise levels can produce a stressful environment for personnel attempting to perform tasks which require high levels of concentration. One cannot expect that noise could be greatly reduced at local control stations within the nuclear power plant environment. However it should be recognized that excessive noise can impair hearing and interfere with communications, as well as contribute to fatigue, irritability, and boredom. Therefore, steps should be taken to control noise levels in any working environment.

Although it is difficult to make the generalization that noise causes a degradation in task performance, there is evidence that certain tasks are affected by noise. Among these are certain mental tasks; tasks requiring skill and speed (Roth, 1968); and tasks requiring high levels of perceptual capability (Boggs and Simon, 1968). Noise which masks communication between two points is of critical concern.

This section presents data obtained from 14 different local control station locations. Appendix H addresses in more detail the problems of noise encountered in the plant and discusses the relation of noise and performance.

Local Control Station Data - Noise

The Occupational Safety and Health Administration (OSHA) has established recommended levels of noise exposure for specific durations in industry jobs. This information is presented in Table 4.4. The dB(A) [or dB-A] measurements shown in Table 4.4 are weighted to account for human hearing response at normal noise conditions and allow noise level to be reported as a single number rather than many levels at different frequencies. Sound level values, including the dB(A) value and octave band center frequency values for 250 Hz, 500 Hz, 1 Hz, 2 kHz and 4 kHz, are included in Table 4.5 for 14 different local control station locations. In some situations readings were taken with equipment operating and again when equipment was not operating to provide a data range.

When comparing the noise level data obtained from local control stations to permissible noise exposures for industrial jobs as specified by OSHA, less than 1% of the data exceeds the 8-hour day, 90-dB(A) limit. The two measurements exceeding the 90-dB(A) limit were obtained at the diesel generator and were considered upper bounds for those locations. This upper bound was defined as that time when machinery was in operation. These noise levels [110 dB(A) and 115 dB(A)] would be considered permissible noise levels for durations of 1/2 hour and 1/4 hour, respectively. This equipment should be verified as an occassional noise producer and not equipment required for continuous operation when local control stations are manned. If outside power were lost, the diesel generator might be "on" continuously for many hours. Standards exist for allowable exposure to intermittent noise (refer to Appendix H, Figure H.3).

TABLE 4.4. Permissible Noise Exposure for Industry Jobs (Federal Register 1971)

Duration Per Day (hours)	Sound Level (dB-A)
8	90
6	92
4	95
3	97
2	100
1 1/2	102
1	105
1/2	110
1/4 or less	115

Once a noise problem is established, several approaches to solving the problem of excessive noise can be taken. They generally include controlling the source (proper design, maintenance, lubrication) isolating the noise (barriers, proper layout), and diminishing the noise (mufflers, baffles, sound absorbers). Ear protection devices are an option when noise levels cannot be reduced to acceptable limits.

4.2.2 Human Factors Engineering Design Deficiencies Present in Local Control Stations

The photographs, environmental measures, and interview results were analyzed to establish the kinds of human factors design deficiencies present in the control stations we examined. Examples from the interview and photographic results are presented throughout this analysis to highlight specific problems. The purpose of this analysis was to discover what kinds of human factors deficiencies may be found in local control stations and to judge (see Section 5.0) how sufficiently NUREG-0700 would address these deficiencies if NUREG-0700 were applied to local control stations. The local control stations we studied appeared to reflect the fact that each nuclear power plant in the U.S. is unique. The control panels we examined were so variable in their quality and features that it was not even possible to compare two panels with the same functions.

TABLE 4.5. Local Control Station Noise Data

ID #	Local Control Stations	dB(A)	dB Value at Octave Band Center Frequency (in Hz)				
			250	500	1K	2K	4K
	Multi-Function Panels						
2-1	Remote Shutdown	82	80.5	80.5	78	73	67.5
	In the Phone Booth	75-76	75-78[a]	72.5	72	66.5	61.5
3-1	Remote Shutdown	73	71.5	73.5	68.5	68	61.5
4-2	Remote Shutdown	75	71	69	65	65	65
1-2	Radwaste Control - Panel	63	64	60	58	54	47
	At the Phone	62	62	61	57	52.5	47
2-2	Radwaste Control	85	89	81.5	76	73.5	67.5
4-1	Radwaste Control	68	63	62	58	55	53
3-2	Hydrogen Recombiner	64	64.5	65	55	48.5	45
1-1	Diesel Gen. Panel (off)	63	57.5	58.5	58	55	53
	" " " (on)	115	113.5	110	111	104	101
	Diesel Engine Panel (off)	67	62	62	62.5	59	58
	" " " (on)	110	107	104	102	97.5	96.5
	Single-Function Switch						
2-3	HPI Makeup Control Valve Actuation	86.25	89	81	77	77	72.5
	Single-Function Valves						
3-3	14-inch Manually Operated Valve to Main Feedwater	89.5	84.5	85	83	80.5	81.5
4-3	Primary Makeup Water Ctrl	83	81	82	78.5	75.5	70.5
	At the Phone	86	83	83.5	82	79	75

(a) Some spikes were recorded off the scale.

The assessment below is necessarily general. A detailed analysis of the components on the panels was not conducted nor were the underlying system requirements determined. Since the plants were in operation during our visits, manipulation of controls or changing the display was not possible. We were invited into the plants at the convenience of the operating personnel, and our objective was limited to surveying only a few local control stations at each plant to determine the general nature and magnitude of any problems that might exist.

We classified the LCSs we studied into three major categories. In the first category are integrated multifunction control panels. The sample in this category included remote shutdown panels, radiation waste (radwaste) control panels, diesel generator panels, and containment hydrogen recombiner panels. The second category included single-function manual switches such as the high-pressure injection switch. The third category included single-function manual valves. The valves studied in this category were the large main feedwater valves and the much smaller primary makeup water control valves. In the section below we describe each of the categories and the major human factors deficiencies observed in each. As the lists indicate, many of the deficiencies were present in more than one of the categories.

4.2.2.1 Integrated Multifunction Control Panels

The local control stations studied in this category included remote shutdown panels, to which operators go in the event the control room must be evacuated. From the remote shutdown panels, operators can bring the plant to a safe condition following scram by controlling primary cooling water flow.

This category also includes radwaste control panels, which are used to monitor, handle, and treat radioactive by-products from the reactor operation, and diesel generator panels, at which emergency diesel function is monitored and locally controlled.

The final type of panel studied in this category was the containment hydrogen recombiner panel at which hydrogen is monitored and controlled to keep the mixture of gases in containment at safe levels during transients.

All of the panels in the category of integrated multifunction control panels are characterized by a large number of different controls and displays arranged on control panels that are very similar in appearance to those found in the main control room. In fact, several of the panels studied (radwaste and hydrogen recombiners) were located in or very near to main control rooms. In contrast, diesel generator panels were located in a very noisy room containing the emergency diesel generator engines, and some of the remote shutdown panels were in locked closets off of plant corridors.

Remote Shutdown Panel

The check list items and interviews with operators at the various multifunction control stations revealed several potential problem areas that relate to the features required of this category of LCS. For example, we found that only one of the three remote shutdown panels visited had written emergency procedures stored at the panel. The emergency shutdown procedures for the other two plants were stored in the control room and would have to be carried to the LCS if the control room ever had to be evacuated. Another problem noted at the remote shutdown work stations was that the emergency lighting was not aimed at the panel at two of the three plants. It was impossible to determine if the lighting would be adequate during an emergency because the emergency lighting system was not exercised during our visit. However, it did appear that emergency lighting would be marginal for tasks such as reading procedures. Another problem at the remote shutdown panel was the lack of seating. Operators could be standing, sitting, or laying on the floor for the extended period of time required to mitigate an emergency situation. One interviewee also expressed the view that temperatures and humidity were too high for sustained manning of the LCS.

Photographs of the remote shutdown panels revealed many, if not most, of the common control panel deficiencies noted elsewhere (e.g., EPRI, NP-2411). Figure 4.4 is a composite photograph of the best-designed remote shutdown panel of the ones examined. Some of the problems noted on it were:

- lack of functional grouping
- ambiguous placement of labels
- label lettering too small for the reading distance
- temporary labels to compensate for inadequate labeling
- poor maintenance that caused missing labels
- inconsistent component names from unit to unit (in multi-unit plants
- unnecessarily detailed labels
- controls with ambiguous pointers
- controls that obscure labels
- parallax problems between the control and position indicator labels

Interviewees noted that more systems and indications were needed to fulfill the intended functions of the panels. An operator at one of the plants noted that their system even required an operator to remain in the control room to control make-up and letdown during a control room evacuation. In addition, labeling deficiencies were noted in the plants. One interviewee suggested there is a need for color coding labels for each unit's LCSs in a multi-unit plant. In one case, he reported, an operator accidentally tripped Unit 1 instead of Unit 2.

Communication problems noted included one case in which the operator thought additional LCS communication equipment was needed for the

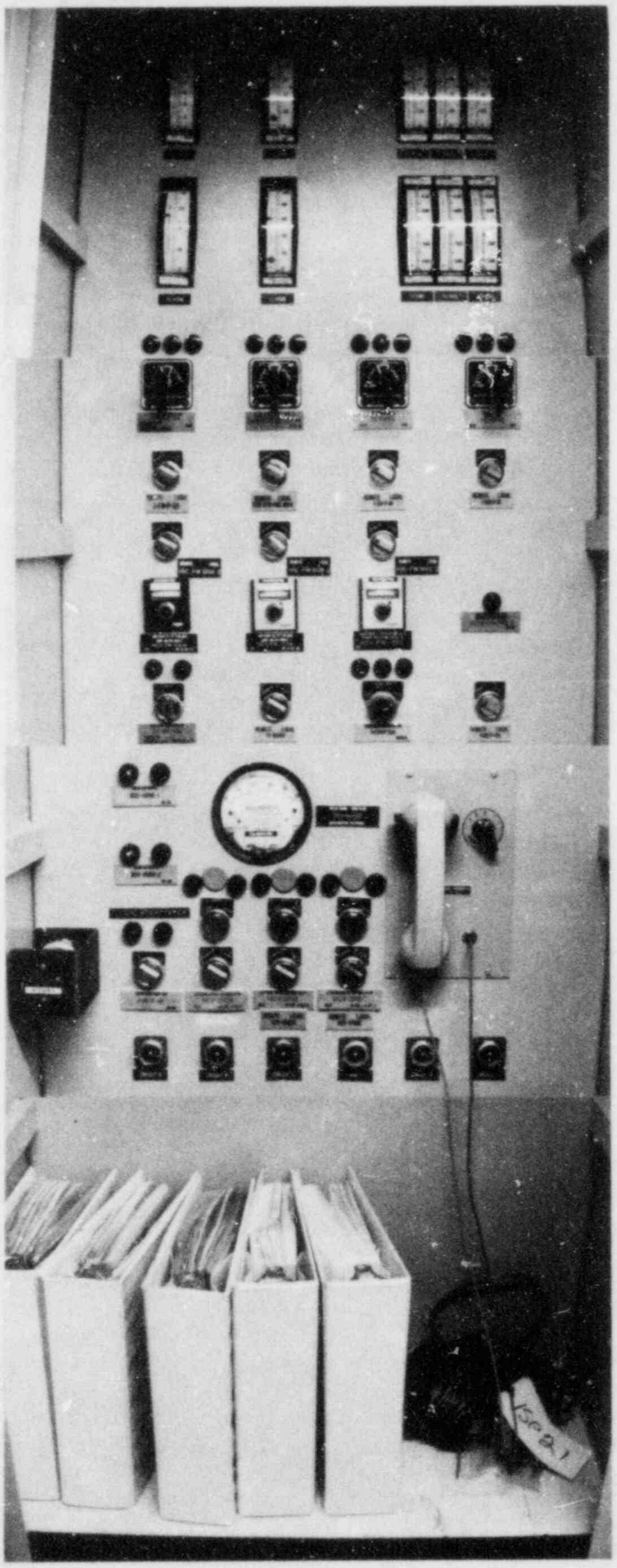


FIGURE 4.4. Composite Photograph of PWR Remote Shutdown Panel

superintendent to be able to call off-shift personnel during an emergency. At another plant, unauthorized use of the plant public address (P.A.) system caused the local noise level to be excessive and could result in interference with access to the P.A. during an emergency.

Radiation Waste Control Panels

Radiation waste (radwaste) control panels were studied at three different plants. These panels ranged from being relatively simple to relatively large and complex. Their operational environments varied according to their plant locations. One was located in the main control room; a second was located in the slightly less controlled environment of a room adjacent to the main control room; the third was located in the noisy and hot environment of a caged-in area on the plant floor. Although the panel located in the main control room was not strictly a "local" control station, its function is separate from the main control room and not specifically addressed by NUREG-0700.

As with the other panels survey, qualified LCS operators were interviewed at the LCS site. The radwaste control operators reported that indicators on the panel are not sufficient to reflect all the important processes going on during operations. One interviewee noted that there was no indication on the panel of such parameters as valve status, flow rates, or levels during centrifuging. Another noted that a private radwaste disposal company was running a portion of the disposal process for his power company. As a result, there was a need for especially good intergroup communications between the radwaste personnel at the two companies. It was also essential that both groups be provided with instrumentation showing flow rates and paths between the two neighboring facilities.

One complaint about annunciators was that they should be disabled when they are flashing for secured, non-operational systems. The flashing of meaningless annunciators masked the flashing of operational annunciators that needed attention.

Human Factors Engineering deficiencies noted at the various radwaste local control stations included:

- hand-drawn mimic and demarcation lines
- hand-printed control and display labels and instrumentation limit values
- poorly designed controls having indicator parallax problems and indistinct pointer arrows
- panels with inconsistent arrangement of red and green indicator light pairs (some switches had green on the left, others had green on the right)

- poor panel maintenance including missing, defaced, or misplaced labels; spilled ink on chart recorders.

Hydrogen Recombiner Panels

The hydrogen recombiner panels are shown in Figure 4.5. These panels were located on flat wall panels in a control room adjacent to the plant's main control room. The panels show obvious signs of poor maintenance. Several labels were missing; other were falling off. The panels were arranged in reverse of the normal practice. Unit 1 panels should have been on the left instead of the right. It appeared that the temperature indicators in the upper left hand corner of each panel had replaced much larger units. As a result, the labels for these displays were improperly located closer to the temperature channel selector switch than to the temperature readout. In addition, the temperature gauge itself is not a well-designed component because its design does not comply with accepted human factors standards. For example, the pointer is much too thin; the scale does not have color bands indicating safe and unsafe operating temperatures; the scale numbering is inconsistent for adjacent equal intervals; and there is no indication for the purpose of the glowing light inside the scale markings on the lower left side of the dial face.

The labels on the panels also have numerous faults. For example, the label meanings are ambiguous. The large dial is marked "temperature readout," but of what? Many labels appear to have fallen off and then been replaced. Temporary plastic embossed labels with numbers like "357" were pasted next to the control marked "power adjust" in the center right area of each panel. It is not at all clear what these values represent.

Also, there is no functional grouping clearly discernable in the panel layout. The components vary greatly in size and, therefore, optimal viewing distance. It is difficult to ascertain the temperature channel selector position because there is no contrast between the black selector handle and the black switch background to set off the shape of the selector handle.

Several positive features of this panel array are that a telephone was mounted adjacent to the panels, the panels are mounted at a medium height on the wall so that no controls or displays are out of reach or sight, and the individual panel numbers (e.g., 2A, 1B) stand out clearly.

To summarize, these hydrogen recombiner panels have a number of human factors design deficiencies. The major categories are:

- poor panel maintenance

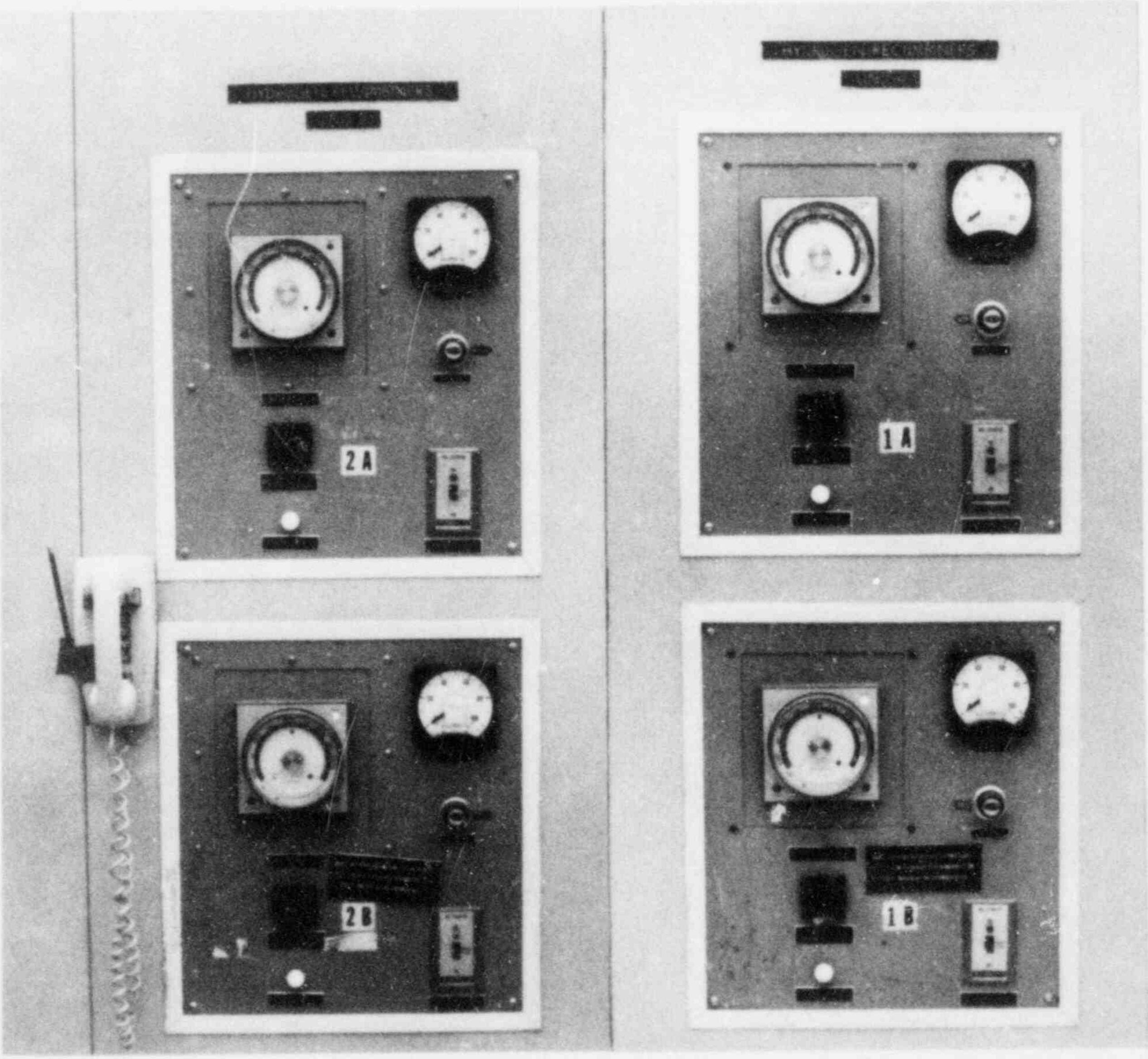


FIGURE 4.5. Hydrogen Recombiner Panels

- poor labeling practices

- poorly designed panel components.

Emergency Diesel Generator Panel

The diesel generator panel that was examined was located in the harshest noise environment in the plant. Noise levels with the generator motors running was measured at 115 dB(A). As a result of the noise and precautions to protect the operator against its effects, certain special human factors engineering considerations must be given to the local control station design. Noise warning features on annunciators become worthless, and communications with coworkers in the diesel generator room and in the plant may become difficult if not impossible. One of the operators stressed the need for "first in" annunciators for adequate trouble-shooting of problems. The panels sometimes show multiple alarms, and when the emergency diesel generator shuts down, the operators cannot tell which was the first alarm. That shows the need for first-in annunciators; a first event may provide no auditory clues.

Another operator reported that because of the noisy environment, the P.A. speaker or phone is often located in another room. Therefore, when problems require contact with the control room, real-time contact is not possible.

The diesel generator panels examined were located next to the diesel generator motor. Among the human engineering deficiencies observed at these panels were:

- poor panel maintenance resulting in old tape marks and dirt that could be mistaken for labels

- handwritten labels including instrument limit values in lieu of color-banded gauges

- inadequate label size hierarchies

- calibration stickers on instrument faces that obscured the dial pointer

- poorly designed components that violated accepted human factors guidelines

- lack of functional grouping

- regular label spacings that make it impossible to discern which label applies to which control or display

- inadequate spacing between components.

4.2.2.2 Single-Function Manual Switches

The only example studied in this category was a switch that actuates the makeup control valve to the high-pressure injection system. This switch is illustrated in Figures 4.6 and 4.7. The plant operators stated that this switch would be manned during any emergency that would cause an evacuation of the main control room. The major environmental problem at this switch was the extremely low light level (less than 3 ft-c). Also, as the figures show, this switch was not properly labeled or maintained.

The major problems noted at this local control station were:

- poor maintenance of the switch and its associated panel
- failure to secure a locked switch
- handmade labeling covering permanent labeling
- switch that lacks a distinct pointer
- only one labeled switch position
- no instructions about breaking glass to gain access
- inadequate lighting
- failure to provide signs directing AOs to the obscurely located switch.

4.2.2.3 Single-Function Manual Valves

These valves vary widely in size and may be found in a variety of environments. The two valves examined in this category were a large 14-in. main feedwater control valve and a very small primary makeup water control valve.

Manually Operated Feedwater Valve

The large main feedwater valve is shown in Figure 4.8. This valve was not labeled, and no proper provision was made for a work platform or other structure from which the valve could be manipulated. The major environmental condition of concern at this valve was the high temperature, which was approximately 90°F. As was pointed out in Section 4.2.1, workers could not be expected to perform for very long periods at such a high-temperature environment. It is also possible that an operator would be required to dress in protective clothing because radiation could also be present if significant leaks developed.

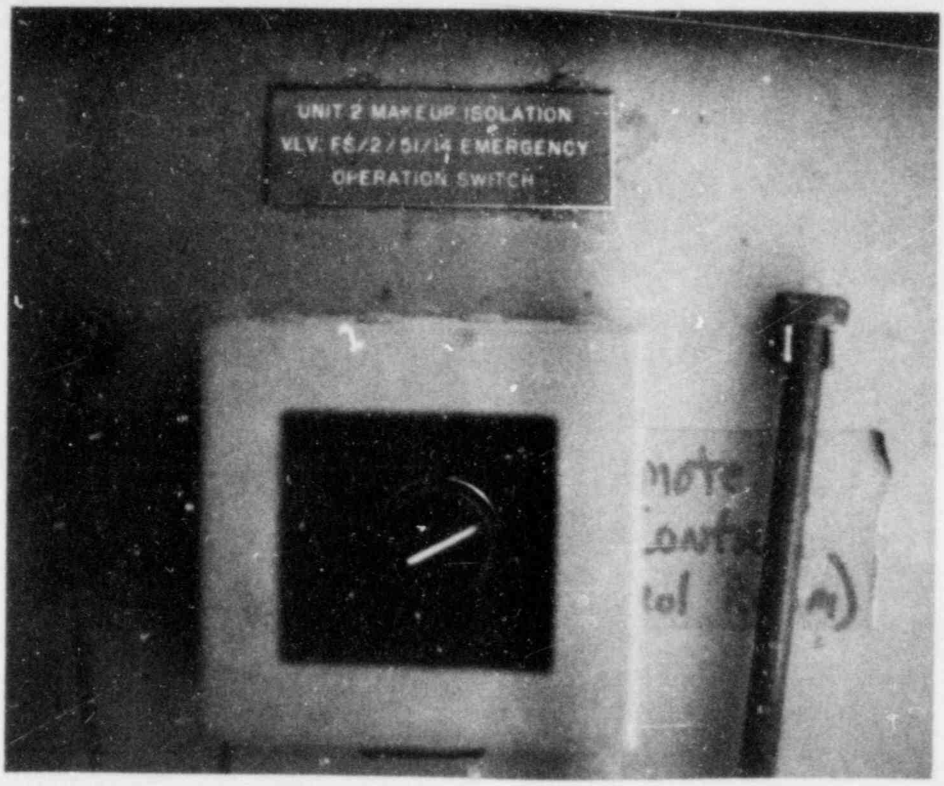


FIGURE 4.6. Actuation Switch for the Makeup Control Valve to the High-Pressure Injection System - cover closed

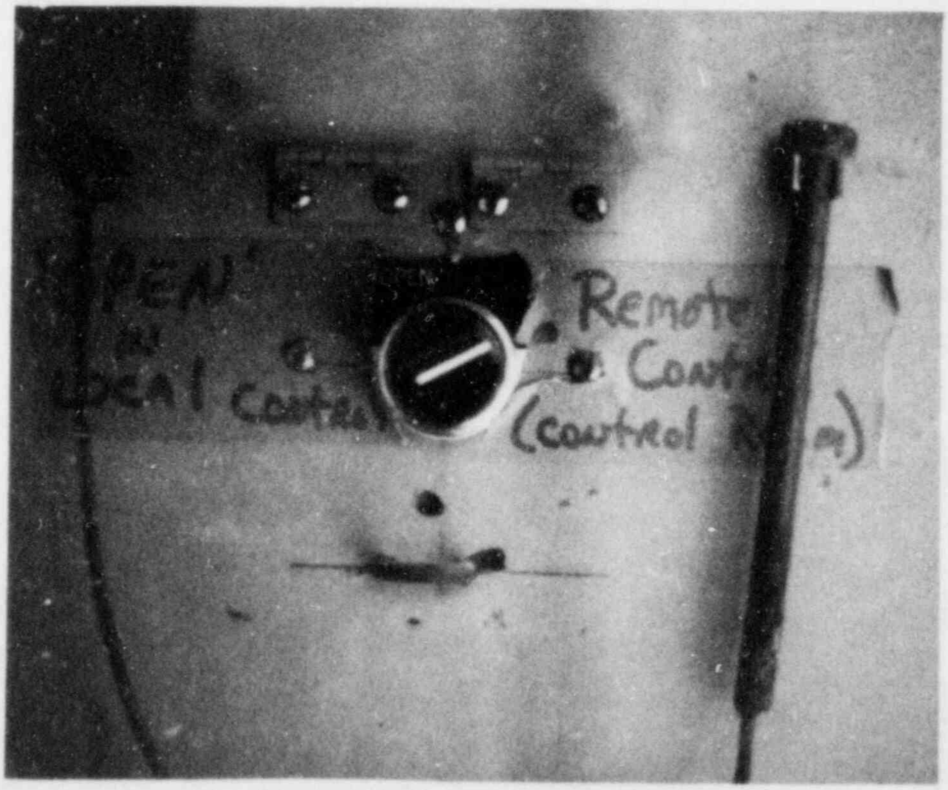


FIGURE 4.7. Actuation Switch for the Makeup Control Valve to the High-Pressure Injection System - cover open

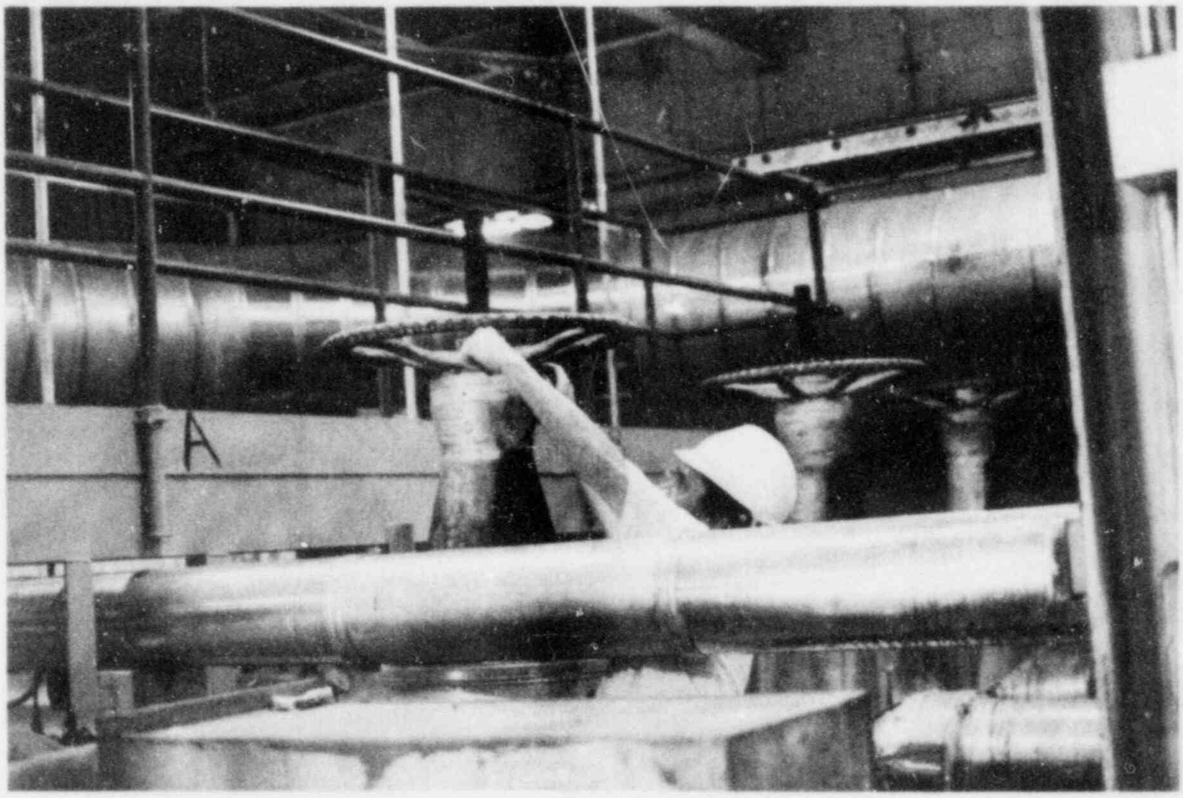


FIGURE 4.8. 14-in. Main Feedwater Valve with No Operator Platform

Primary Makeup Water Control Valve

The second valve in this category, the primary makeup water control valve, is shown in Figure 4.9. The valve controls the amount of primary grade water that is blended with borated water to achieve correct neutron absorber concentration for reactivity control. Manipulation of the valve is required to prevent a reactivity dilution accident when the unit is shut down. This valve was located in a very dark area of the plant (less than 7 ft-c) and was mounted fairly close to an area that would become highly radioactive during a transient (the "let down" is behind the near wall). It would be somewhat difficult to manipulate by a suited operator because of its proximity to the floor and adjacent pipes. A telephone was located about 18 feet away from the valve and would have to be used to coordinate the blender operation with the reactor operator. The operator interviewed reported

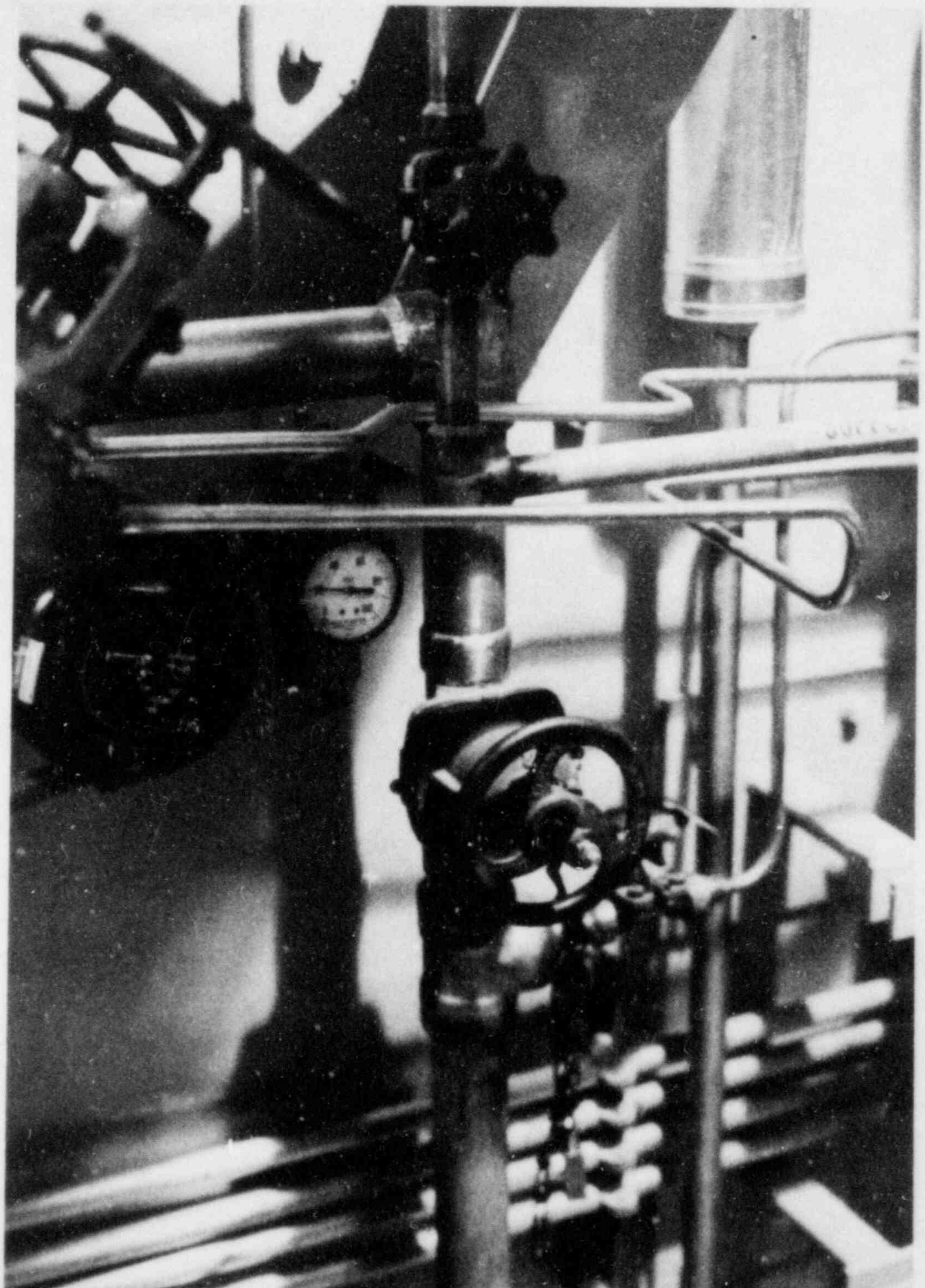


FIGURE 4.9. Manually Operated Control Valve for Primary Makeup Water

that he had two problems with plant communications. First, the five-channel P.A. is easily tied up by multiple users. Second, the plant amplifiers for the P.A. are usually turned down during an outage. Then, during subsequent normal operations, communications cannot be heard because the amplifiers usually are not turned back up.

The major human factors deficiencies associated with the single-function manually operated valve LCSs were:

- high ambient temperatures
- potentially high radioactivity levels
- inadequate illumination
- failure to provide facilities (e.g., platforms) from which the large valve could be manually operated
- inadequate labeling of valves
- failure to design the valves so their operational status (open or closed) could be easily determined
- poor communications due to inadequate P.A. system capacity
- poor communications due to failure to restore P.A. system volume following an outage
- telephone located away from a primary LCS that requires communications

5.0 ADEQUACY OF NUREG-0700 FOR APPLICATIONS TO LOCAL CONTROL STATIONS

In 1981 the NRC published NUREG-0700 for use as a guide in conducting control room design reviews required by the NRC Action Plan developed as a result of the TMI-2 Accident (NUREG-0660). The check list items contained in the document cover almost every human factors aspect of control room design. The NRC is also interested in alleviating operator errors that might occur at other safety-related control stations. The purpose of this study was to assess the adequacy of NUREG-0700 for application to local control stations. The results of that determination are presented here.

5.1 APPLICABILITY OF NUREG-0700 SECTIONS

Section 4.2.2 of this document pointed out many examples of the variety now present in local control station designs. This variety makes it impossible to say unequivocally that any particular section of NUREG-0700 is not relevant to the design of LCSs. It is probable that some part of every section could apply to some safety-related workstation somewhere. Nevertheless, the various sections of NUREG-0700 are summarized below based on our experience with the sample of local control stations described in this study. These very brief summaries attempt to point out the main strengths and weaknesses of the document sections.

The first four sections of NUREG-0700 relate to the process, planning, review, assessment, and implementation of control room human factors improvements. These sections appear to be applicable to similar efforts performed on local control stations; the major difference would be in the scale of the effort.

NUREG-0700, Section 6.1 (Control Room Workspace) contains useful information about spacing required between pieces of equipment, document organization, and storage. This information could apply to local control stations requiring written procedures. The section also contains information on the anthropometric basis for equipment dimensions that should pertain as readily to local control stations as to main control rooms. The section on standup console dimensions is particularly valuable since many local control stations fall into this category (e.g., remote shutdown panels). The section on sitdown consoles could also prove valuable in some cases (e.g., some radwaste panels). One useful part of the Sitdown Console Subsection (6.2.1.7) is information on desk space requirements for laying down documents such as procedures. NUREG-0700 information on sit-stand workstations is typical for human factors guideline documents and is applicable because many types of local control stations are sit-stand workstations. The section on Unit Mirror Imaging could be useful in situations where the plant has two units and has located matched panels close to one another. Section 6.1 also contains subsections on temperature, humidity, ventilation, sound, illumination, and emergency lighting. Unfortunately, however, many of these sections do not cover an adequate range of conditions likely to be found at local control stations (see Sections 4.2.1 and 5.2.2 in this document for a more detailed discussion of this issue).

Much of the NUREG section on communications (Section 6.2) appears to be applicable to local control station usage. The only category that may need to be added would be a special section dealing with communications in extremely noisy environments. In addition, appropriate subsections should have warnings that they might not be applicable in certain environments. For example, the section on auditory coding techniques could not be applied to every local control station since auditory coding would be impossible in a noisy environment. Section 5.2.2 of this report discusses this problem in more detail.

NUREG-0700, Section 6.3 deals with annunciator warning systems. In the context of the comments made in the section above, there should be warnings regarding use of annunciators in unusual environments. Auditory alarms may not be workable. Moreover, visual alarms may need special provisions such as brighter intensities and greater contrast to make the alarms more noticeable when emergency situations occur.

NUREG-0700, Section 6.4 is concerned with controls. Many of the same controls used in control rooms may be used at local control stations, especially those in the first category of integrated multifunction control panels (see Section 4.2.2.1 of this report). However, many local control stations involve the operation of hydraulic valves. Section 6.4 does not address this type of control at all. (This problem is discussed in more detail in Section 5.2.1 of this document.)

NUREG-0700, Section 6.5 deals with displays. Most of this section would apply to local control stations (the major exception in existing plants would be use of CRTs). Many of the subsections relate to the design of components; these discussions could be useful aids in selecting well-designed parts for use in local control stations.

Section 6.6 on labels and location aids is probably the most useful part of NUREG-0700 because labeling is one of the most common faults of local control station designs and also one of the easiest to fix. The only additions to this section for application to LCSs might relate to changes in labels (size and color) in situations where the lighting level is low.

Section 6.7, which refers to process computers, was not judged to be relevant to local control stations. However, the section might relate to LCSs in the future should LCSs become more sophisticated.

Sections 6.8 (Panel Layout) and 6.9 (Control-Display Integration) both appear applicable to local control stations. However, many of the recommendations contained in these two sections could involve the redesign or at least substantial modification of existing control panels.

5.2 DEFICIENCIES OF NUREG-0700 RELATIVE TO ITS APPLICATION TO LCSs

Only two clear areas of deficiency were found in NUREG-0700 relative to its application to LCSs. First, the document does not adequately address the human factors design criteria of manually controlled valves. Second, it does not adequately address human factors design requirements for workstations that are subjected to extreme environmental conditions.

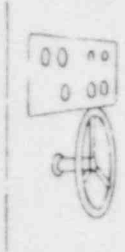
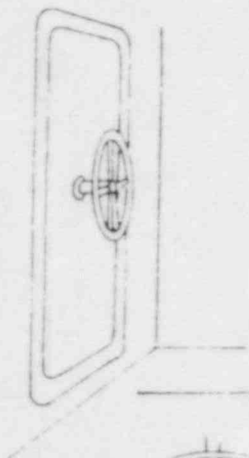
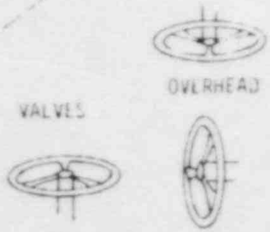
5.2.1 Single-Function Manually Controlled Valves

The NUREG-0700 section on controls (Section 6.5) does not address the design of manually controlled valves. However, many safety-related local control stations consist solely of valves (see Section 4.2.2.3 of this document). Two good sources of information about the design of manual valves are the Human Engineering Guide to Equipment Design (VanCott and Kinkade, 1972) and Military Standard 1472C (U.S. Department of Defense, 1981).

Section 8.3.1 of VanCott and Kinkade contains some general principles of control design that apply to valves. These include recommendations on control forces and operator anthropometry; "natural" control movement; "feel" and resistance; design to withstand abuse; indication of control position (in very general terms); and surfaces to prevent slipping. In the same document, Section 8.3.2 contains a subsection on "valve controls" (p. 356). In addition, Section 8.5.2 contains a subsection on "handwheels" that can be applied to manually operated valves.

A military standard (MIL-STD-1472C, Section 5.4.1.2.4) describes rotary valve motion stereotypes. It recommends valve opening with a counterclockwise motion and also recommends that valve controls be provided with double-ended arrows showing the direction of operations. The arrows should be labeled at each end to indicate the functional result (e.g., open and close). Another section of MIL-STD-1472C (Section 5.4.2.2.5) deals with two-hand operated hand wheels such as those commonly found on manually operated valves in nuclear power plants. That section presents guidelines for when such controls should be used; types of turning aids (e.g., knurling, indentation, high-friction covering) that can be used to improve application of torque; and dimensions, resistance, displacement, and separation of handwheel controls. Table 5.1 shows MIL-STD-1742C, design recommendations for handwheels

TABLE 5.1. Handwheel Design Guideline Applicable to Manually Operated Valves in Nuclear Power Plants (MIL-STD-1472C)

CONFIGURATION EXAMPLE	APPLICATION CRITERIA	DESIGN CRITERIA				
		DIMENSIONS			DISPLACEMENT	SEPARATION
		DIAMETER	RIM DIAM	MIN HAND CLEARANCE		
	CONTINUOUS ADJUSTMENT FOR ALTERNATE SLEWING/PRECISE POSITIONING, USING DISPLAY REFERENCE. RESISTANCE LOW (e.g., BELOW 110 N (25 lb)	200-510 mm (8-20")	19-32 mm (3/4 - 1-1/4")	75 mm (3") around rim	See control/ display ratios 5.1.4	710 mm (28") elbow-elbow clearance
	CONTINUOUS LOCK-UNLOCK OPERATION	200 mm (8") for 22 N (5 lb) to 510 mm (20") for 155 N (35 lb)	19-32 mm (3/4 - 1-1/4")	75 mm (3") around rim	N/A	710 mm (28") elbow-elbow clearance
	HIGH TORQUE VALVES	200-400 mm (8-16") for overhead; 200-510 mm (8-20") for other positions; 300-1520 mm (12-60") abv standing surface	19-32 mm (3/4 - 1-1/4")	75 mm (3") around rim	See 5.1.4 when applicable	710 mm (28") elbow-elbow clearance

like those used on nuclear power plant valves.

A subject not found in either NUREG-0700 or MIL-STD-1472C is the design of valves so operators can easily tell whether they are open or closed. Such a information could make a major contribution to nuclear power plant safety if it were widely adopted by component manufacturers and workstation designers.

5.2.2 Design Requirements of Workstations in Extreme Environmental Conditions

NUREG-0700 does not address the human factors design requirements for workstations in extreme environmental conditions. As pointed out in Section 4.2.1 of this document, some local control stations are subjected to temperature, humidity, illumination, and noise conditions that vary significantly from normal control room environments. NUREG-0700, Section 6.1.5 (Environment) only describes desirable environmental condition ranges and some of the consequences of values that fall out of normal bounds. No part of the section provides guidance for effecting solutions or design modifications that adapt the workstation to unsatisfactory conditions. However, this kind of information is available from common human factors reference sources such as VanCott and Kinkade (1972) and MIL-STD-1472C (U.S. Dept. of Defense, 1981). VanCott and Kinkade, for example, suggest that in noisy environments loud speakers should be placed near the operator's ears so that he or she can adjust speaker gain so as not to contribute to overall noise level (Section 9.5.6). For another example, MIL-STD-1472C suggests adaptations in label size for various luminance levels as shown in Table 5.2 (MIL-STD-1472C, p. 121). Both of these examples point out the kinds of adaptations to guidelines or check lists that are required to help designers produce workstations that are less likely to induce operator errors in hostile environments.

TABLE 5.2. Guidelines for Label Size Versus Luminance (From MIL-STD-1472C)

MARKINGS	HEIGHT*	
	3.5 cd/m² (1 ft–L) OR BELOW	ABOVE 3.5 cd/m² (1 ft–L)
For critical markings, with position variable (e.g., numerals on counters and settable or moving scales):	5 – 8 mm (0.20–0.31 in.)	3 – 5 mm (0.12–0.20 in.)
For critical markings, with position fixed (e.g., numerals on fixed scales, controls, and switch markings, or emergency instructions):	4 – 8 mm (0.16–0.31 in.)	2.5 – 5 mm (0.10–0.20 in.)
For noncritical markings (e.g., identification labels, routine instructions, or markings required only for familiarization):	1.3 – 5 mm (0.05–0.20 in.)	1.3 – 5 mm (0.05–0.20 in.)

*Values assume a 710 mm (28 in.) viewing distance. For a distance, D, other than 710 mm (28 in.), multiply the above values by D/710 mm (D/28 in.).

6.0 APPROACHES TO SOLVING THE PROBLEM OF POOR LCS DESIGN

This section presents strategies for effecting improvements on workstations in both existing and future plants. One of the strategies for improving existing plants--making simple and inexpensive modifications--is presented in more detail so that a utility using this document can see which kinds of changes are judged to be least expensive and most likely to reduce human error.

6.1 SIMPLE LCS IMPROVEMENTS THAT COULD REDUCE OPERATOR ERRORS AT EXISTING POWER PLANTS

Several simple modifications to control panels and workspaces can produce significant reductions in the probability that human error will occur in conjunction with the operation of local control stations. The modifications fall into the six major categories detailed in the following discussions: workspace improvements, control panel improvements, communications, procedures, environment, and maintenance and housekeeping. A limited task analysis of the LCS operator's job would be helpful in determining what modifications would be most beneficial.

The process of designing and implementing these modifications should employ one of the most important precepts of human factors engineering: users of the the system should be thoroughly involved in the modification process. This means that users should be consulted about their working experience with the local control station; they should be asked to suggest improvements for mitigating any deficiencies they have experienced; and, following implementation of their suggestions in conjunction with the guidance in NUREG-0700 and similar documents, they should be asked to evaluate all proposed changes. This procedure would serve three purposes: the new changes would better meet the needs of the system users; it would increase user acceptance of the modifications to the existing system; it would reduce the retraining time to reach or surpass original operating performance levels.

6.1.1 Understand the Operator's Job

It is highly unlikely that existing local control station designs were based on thorough task analysis. Therefore some effort should be made to assess the operator workload that is likely to occur during local control station operations to be sure that, in fact, the tasks can be performed under the expected conditions and with the expected staff. Section B4.3.2.6 of NUREG-0700 provides a general description of workload assessment. It may be necessary to perform a form of task analysis on the operator's job in order to make workload determinations in support of human factors assessment of LCSs. This task analysis need not be very elaborate or detailed, only adequate for the purpose.

It should be understood that task analysis is a technique that is usually customized to gather organized information that satisfies a particular need. In this case, the adequate task analysis information could probably be collected through user interviews based on a simple walk- through of the existing emergency procedures that apply to each particular LCS. The end product of such a task analysis would be a timeline (or step-by-step) listing of tasks the LCS operator must perform. This listing would then be studied to determine if any conflicts or demands placed on the operator would preclude him from meeting his operational responsibilities. The primary benefit of this analysis would be to define some basic workstation needs. For example, if the operator is required to watch and report on a display but the only means of communication is located on the other side of a locked door, he may not be able to perform his task quickly enough. Such findings can help guide the types of changes that might be most effective in reducing operator error probabilities.

6.1.2 Improve the Workspace

In general, all aspects of the workspace that are likely to be used by the operator as he performs his tasks should be integrated into a single workspace design. None of the local control stations we studied provided seating for the operator, nor was it common to find a writing surface or laydown area for procedures manuals or other reference materials. At the same time, it appears that many of the emergency scenarios that might require operators to man safety-related local control stations are also likely to require them to stay at their posts for long periods of time. For example, one operator expected that he would have to sit on the floor near the local control station during a real event because he would have to be there for such a long time. Therefore, one of the simplest improvements that could be made to LCSs would be to provide a chair or stool. Laydown space for procedures is also essential because procedures must be relied upon in bringing the plant to safe shutdown, especially under conditions of stress that might be expected during an emergency. Therefore, a convenient, well-lit, writing surface should be added to workstations requiring use of written procedures. Another simple workspace improvement would be to move auxiliary components like telephones and bookshelves to within reach of the working operator. These workspace improvements should increase the probability that the operator will maintain his alertness, follow his procedures, and communicate with others more effectively and expeditiously.

6.1.3 Improve the Control Panel

A number of simple, inexpensive improvements can be made to control panels to improve their usability. Section 6.6 in NUREG-0700 can be used as a guide to improve labels on all panels, controls, and displays. These labels should be developed jointly with the control station operators to ensure their accuracy and applicability, and then they should be affixed temporarily to allow a user evaluation. Once the users agree on the new labels, they should be made permanent.

Special attention should be paid to evaluating any temporary labels presently found on the panels since these may constitute unsatisfied needs already identified by the user.

Another improvement is to add lines that clarify the panel controls and displays. These might be merely demarcation lines that separate functional groups, or "mimic" lines that better identify system functions by using shapes or by indicating the direction or order of processes. In some cases it may also be prudent to use distinctive color coding of labels, controls, displays, or panel sections to denote separate systems or units. In general, it is desirable to use multiple techniques for control and display coding (e.g., labels, functional grouping, shape, and color) as long as they aid the operator's task and do not interfere with one another.

A final, and potentially very valuable, control panel improvement is to check the local control station for controls, displays, or labels that violate "population stereotypes" and then correct any deficiencies. Population stereotypes may be thought of as "what most operators expect" when they use a control or display or when they try to locate a component on a panel. It should be noted that some stereotypes are natural, e.g., turning a wheel clockwise to turn right; others are traditional, e.g., turning a faucet clockwise to shut off water. The best way to assess the population stereotypes applicable to a local control station is to consult with the users and reference sources for the user population (e.g., U.S. Military Standards for U.S. populations).

Table 6.1 provides come common stereotypes for direction of control movements. Other stereotypes exist for colors (e.g., green for safe or go, red for danger or stop), display movements (e.g., clockwise or up to increase, counterclockwise or down to decrease), panel layouts (e.g., arranging sequential components from top to bottom and left to right), and even relationships between components (e.g., the display that goes with a particular control is the one closest to it). It should be noted that Table 6.1 does not apply to rotary valves. Traditional direction of movement for rotary valves is clockwise to close (stop flow) and counterclockwise to open (start flow).

Once violations of stereotypes are discovered, they should be eliminated if possible. Studies report that operators are at least 10 times more likely to commit errors if their controls or displays violate strong populational stereotypes (Swain and Guttman, 1981, p. 3-72). Unfortunately, it may be very costly or even impossible to correct some violations on existing panels. In such cases, special coding and operator training should be applied to mitigate the problem as much as possible.

TABLE 6.1. Direction-of-Movement Stereotypes for U.S. Populations[a]

Function	Control Action
a. On, Start, Run, Open	Up, right, forward, clockwise, pull
b. Off, Stop, Close	Down, left, backward, counterclockwise, push
c. Right	Clockwise, right
d. Left	Counterclockwise, left
e. Raise	Up
f. Lower	Down
g. Increase	Forward, up, right, clockwise
h. Decrease	Backward, down, left counterclockwise

(a) From NUREG-0700, Section 6.4.2.1

6.1.4 Enhance Communications

Communications are especially important in the operation of the major safety-related local control stations (e.g., remote shutdown panels) because they are frequently used as command posts from which the activities of other operators are controlled. One communications problem we observed was the unauthorized use of the P.A. system by temporary personnel. This use took the form of verbal graffiti and was very disruptive to plant activities. It is conceivable that such disruptions could occur during emergency or critical LCS operations and cause them to lack proper coordination. It is, therefore, recommended that the telephone/P.A. system be made secure from unauthorized users.

Amplifiers should be added to telephones that are located in noisy environments; telephone bells in such environments should be supplemented with properly placed flashing lights. If headsets are used, the headsets should be adjustable to a total range of users and comfortable when worn for long periods. Relevant telephone numbers and call signs should also be displayed adjacent to the phone dials, switches, or jacks.

6.1.5 Increase the Availability of Procedures

A complete set of applicable operating procedures should be permanently located at each local control station within easy reach of the operator's position. In several of the plants we studied, operators were required to bring the appropriate emergency procedures with them from the main control room to the local control station when an emergency occurs. This deficiency creates one more opportunity for human error during a serious event. In many cases, it may also be possible to display abbreviated versions of procedures, graphs, or check lists adjacent to relevant controls and/or displays to function as job performance aids.

6.1.6 Improve the Operating Environment

Many environmental conditions constitute performance shaping factors that can increase the probability of human error. Fixes should be made to local control stations and their environments to minimize adverse effects of such factors. For example, every effort should be made to mitigate temperature extremes at local control stations by providing insulation, heaters, or fans to improve conditions at the workspace. Similarly, when loud noise sources are present, noise-absorbing material should be installed around the source. Lighting is important: emergency lighting should be tested to ensure its adequacy under worst-case emergency scenarios. A commonly observed fault of emergency lighting was that it was not properly aimed to support the local control station operation.

6.1.7 Upgrade Maintenance and Housekeeping

Even the best human factors design can be neutralized by poor maintenance that allows bulbs to burn out, labels to fall off, or dirt to jam controls or obscure labels or displays. Maintenance should be performed on local control stations to bring them up to the original design standard and keep them there.

6.2 IMPROVEMENTS TO LOCAL CONTROL STATIONS IN FUTURE POWER PLANTS

All future nuclear power plants should require comprehensive human factors involvement from the earliest phases of design through the entire life cycle of the plant. Designers should ensure the total integration of humans into the system operation and maintenance. All workstation designs should comply with accepted human factors standards such as those presented in NUREG-0700.

Moreover, the individual control or display components incorporated in the construction of local control stations (or any other workstations for that matter) should also comply with human factors standards. No matter how much a human factors designer might wish to produce a good integrated control panel, he or she may not succeed because of problems resulting from the use of poor components. Most of the workstation components currently being used have been derived from poorly designed antecedents that never were designed to conform with human factors guidelines. Good examples of this phenomena are the unnecessarily large switches and displays that are commonly used on nuclear power plant control panels. Many of these large switches are holdovers from the days when large switches in the first fossil fuel plants were required to directly switch large voltages. The problem with poor components that do not meet accepted human factors design criteria is not unique to the nuclear power industry. The mining industry, for example, also typically employs poorly designed and antiquated components. What distinguishes nuclear power workstation components from those in other industries are the consequences of operator error. The best panel designs only lead the operator to the right control or display. If that control or display is itself poorly designed, the user may still be trapped into committing an error.

The notion that individual components should comply with human factors standards may merit special NRC research to identify control/display problems that are unique to the nuclear industry. A useful goal of this type of research would be to produce a set of standard designs for the most commonly used controls and displays. Other studies conducted by PNL researchers (Lewis, 1983) have shown that poor human factors design of manually controlled valves out in the plants may similarly lead to human errors that cause systems to be inoperable. Many current valve designs make it impossible for auxiliary operators to tell whether valves are open or closed just by looking at them. It appears, then, that components in the balance of the plant (also local control stations if a broad definition is used) may suffer deficiencies similar to those commonly associated with the local control stations we studied. Since valves throughout the plant may affect all of the safety systems, these components should also meet human factors standards in future plants.

6.3 PROBLEMS ANTICIPATED WITH FUTURE LOCAL CONTROL STATIONS

During the course of the project, local control stations were discussed with knowledgeable human factors professionals. One problem that was mentioned on several occasions concerned the allocation of system functions between men and machines in semi-automated systems. Generally stated, the problem is that as systems become more automated, the role of the human operator changes from one of active participation and interaction with system functions to one of monitoring system functions. The operator's job is thereby changed significantly. The routine job is simplified; some controls and displays are eliminated; a person with lower qualifications is selected to perform the job, and that person receives less training. When an unexpected event occurs in such a setting, the operator may not be able to respond properly to mitigate the situation because he has insufficient training and/or insufficient controls and displays. There are accident data that suggest that this problem is already present in some current systems (e.g., the radwaste spill described below). It is also highly likely to occur in others as more and more system functions are computerized.

To better understand this problem and its implications for future local control stations, a little background information is in order. The traditional hard-wired displays commonly used in nuclear power plants give the control panel designer little choice about how information should be displayed. Each display device handles a single input which is then presented directly to the operator. The only information processing factors that designers can manipulate in such panels concern whether the data should be displayed using dials, edge meters, or some other devices. The designers then arrange the displays in some orderly fashion on a control panel so the operator can locate the information more efficiently. Designers of such panels have no opportunity to selectively display data or to aggregate it into higher level summaries. Consequently, such traditional control panels place a high burden on the human operator who is responsible for analyzing the data, accepting or rejecting data according to the needs of a problem, and forming it into meaningful information that can be used to support a decision.

Hard-wired control/display panels have almost always been developed using what Mitchell (1983, p. 268) calls a "system-centered" approach that basically makes everything automated that can be automated and then gives the human operator everything that is left over. In such systems, man represents the flexible component in the design. Even as systems have become more automated, the systems-centered approach has prevailed as man has continued to be retained as a backup component in the control loop to act as insurance against total failure of the machine. Unfortunately, when the operator of such a system performs normal operations he usually does not have the chance to interact with the system in a meaningful way. Yet in an emergency he is still expected to revert to manual control to keep the system from going awry.

Having the operator in such a dual role creates a number of severe problems that can lead to operational errors. Among these problems are training, boredom, and design adequacy. Personnel using automated systems must have dual training that enables them to function as supervisors when the system is working automatically or as manual controllers when the system is operating during emergency or degraded conditions. The two roles are not necessarily compatible or complementary. They may require different sets of knowledges and skills. Another problem involves boredom. When the system is operating automatically, the operator has little to do and may become bored or complacent. Then when an emergency occurs, he or she is prone to committing errors. Another problem is that automatic systems may not display enough information to enable the operator to know what is going on at any given time. It, therefore, becomes impossible for him to respond properly when an emergency develops.

By way of real life examples, one of the operators we interviewed for this project described a radwaste control panel that did not display valve status, flow rates, or levels during centrifuging. He complained that it was impossible for him to know what was going on inside the system during critical operations. One foreign radioactive waste control accident that resulted in a spill of radioactive water into the ocean was caused by a very similar situation. In that case, the automatic system failed to make a proper transfer of waste material from one tank to another. A combination of human factors problems (e.g., an annunciator light that was always on happened to be near the critical annunciator light) led to the initial failure to quickly detect the event. But the most critical aspect was that once the problem was discovered, the operators apparently were unable to diagnose what was happening because so many of the functions had been automated and their training did not prepare them to make a rapid diagnosis using the information that was available. These two examples point out the fact that function allocation problems are even found in current-generation models of local control stations and that the problems are not trivial.

Future local control stations are even more likely to face these kinds of problems as computers are incorporated into more and more systems. There already are theoretically approaches to solving the problem. For example, one possible solution to these problems is dynamic allocation of tasks instead of static allocation of tasks. This allocation approach is based on the premise that there are many tasks that can be handled by either the human or the computer system. The idea is that a particular task would be allocated to the controller (human or machine) with the most resources available at the time. However, it may take some new technologies--artificial intelligence, for example--to actually put this approach fully into practice.

The human factors profession at present has little understanding of the impact of computer technology on functional allocation between humans and automated systems even though the problem looms over many industries. For example, the latest generation of passenger aircraft employs two-man cockpits instead of three-man cockpits; almost all of the flight operations are automated from just after lift-off at the start of the flight until roll-out on the surface of the destination runway. The Federal Aviation Administration is increasingly concerned with the possibility that the pilots of the new aircraft may not be able to respond to emergencies when they are required to do so. Such cockpits may well be the prototypes for the power plant local control stations of the future. The challenge for human factors engineers and the nuclear power industry is to produce an operator/machine system that optimizes the respective roles of the operator and the semi-automatic system so they can function symbiotically. The challenge for the NRC is to be ready to make rational judgments about such systems so that public safety is protected.

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APPENDIX A

SAFETY SYSTEM FUNCTIONS

SAFETY SYSTEMS FUNCTIONS

1. Emergency Core Cooling(1c*)
2. Postaccident Containment Heat Removal(1c)
3. Postaccident Containment Atmosphere Cleanup(1c)
4. Reactor Shutdown(1d)
5. Residual Heat Removal(1d)
6. Spent Fuel Cooling(1d)
7. Monitoring of Systems Important to Safety(1k)
8. Actuation of Systems Important to Safety(1k)
9. Reactivity Control (e.g., control rods, control rod drives, boron injection)(1m)
10. Electrical and mechanical devices/circuitry between process and input terminals of actuator systems involved in generating signals that initiate protective action(1j)
11. Cooling for systems functions (1), (2), (3), (5), (6) above by cooling water, component cooling and auxiliary feedwater systems(1g)
12. Cooling and seal water for functioning of reactor coolant system components important to safety (e.g., reactor coolant pumps)(1h)
13. Supplying fuel for emergency equipment(1i)
14. Primary and secondary reactor containment(1o)
15. Control safe habitability for personnel and safe environmental limits for vital equipment in the control room(1n)
16. Control release of radioactive effluent
17. Supplying emergency electric power needed for functioning of safety systems 1-16 above(1q)
18. Functioning of systems not otherwise required to continue except that failure to do so could reduce functions included in items 1-16 above to an unacceptable safety level or could result in incapacitating injury to occupants of the control room(2)

*References the numbering in USNRC Reg. Guide 1.29 (Rev 3, 9/78)

APPENDIX B

FORM USED TO DETERMINE LOCAL CONTROL STATIONS OR INTERFACES INVOLVED IN SIGNIFICANCE SAFETY ACTIONS

LOCAL CONTROL STATIONS OR INTERFACES INVOLVED IN SIGNIFICANT SAFETY ACTIONS*

Safety System Function (Number**)	System Name	LCS or Interface Name or I.D.	Transients/ Accidents for Which LCS/ Interface is Required	Anticipated Environmental Conditions at LCS/Interface	Operator Task Requirements	Operator Constraints Including Communications	Other Comments

* e.g., LCS that control or effect the control of safety systems, as well as release of radioactive effluent
** See accompanying list: "Safety Systems Functions"

APPENDIX C

POWER PLANT EVENTS AND MALFUNCTIONS

APPENDIX C

POWER PLANT EVENTS AND MALFUNCTIONS

1. Loss of coolant (LOCA)

   Model the effects of various sized leaks caused by various malfunctions. Examples of these malfunctions are:

   a. Cracks and ruptures of major RCS, steamline, condensate, and feedwater piping
   b. Failure of instrumentation penetrations
   c. Leaks into component cooling water from credible sources
   d. Leaks in the cleanup, makeup and letdown piping outside of containment.

2. Loss of instrument air

   a. Loss of compressor
   b. Variable leaks
   c. Accumulator failure
   d. Loss of service air

3. Loss of electrical power

   a. Loss of generator output / loss of single phase
   b. Loss of normal offsite power / degraded grid
   c. loss of alternate offsite power
   d. Loss of one/all emergency diesels
   e. Loss of selected MCCs
   f. Loss of selected M/G sets
   g. Loss of 4160 VAC bus(es)
   h. Loss of 480 VAC bus(es)
   i. Loss of 250 VDC bus(es)
   j. Loss of 125 VDC bus(es)
   k. Loss of 120 VAC bus(es)
   l. Loss of inverter(s)
   m. Deenergization of individual instruments

4. Loss of reactor coolant flow control

   a. Recirculation flow control failure
   b. RCP eccentricity / vibration
   c. Loss of seal / loss of seal water / loss of lube oil
   d. Single/multiple recirc pump/RCP trips
   e. Single/multiple trips of feedwater, condensate, and condensate booster pumps

5. Loss of condenser vacuum control

   a. Loss of circ water
   b. Loss of condenser hotwell level control
   c. Steam jet air ejector failure
   d. Condenser tube rupture
   e. Condensate / condensate booster pump failure
   f. Variable failure of vacuum breakers
   g. Condenser

6. Loss of service water

   a. Loss of non-safety system service water
   b. Loss of circ water main makeup capability
   c. Loss of safety system (ESF) service water
   d. Loss of RHR service water

7. Loss of shutdown cooling

   a. Loss of RHR (residual heat removal) systems
   b. Loss of steam generator secondary heat removal capability
   c. Loss of spent fuel pool cooling

8. Loss of component cooling

   a. Loss of containment equipment component cooling
   b. Loss of auxiliary equipment component cooling
   c. Loss of emergency equipment component cooling

9. Loss of feedwater - excess feedwater

   a. Loss of main feedwater - loss of MFP valve control, MFP turbine valve failure, master feedwater flow control failure, steam generator level control failure, pump trip
   b. Loss of auxiliary/emergency/standby feedwater - control or block valve failures, turbine valve failures, pump trip

10. Loss of neutron flux indication

   a. Malfunction of shutdown nuclear flux instruments
   b. Malfunction of all neutron flux indication - failed high/low, under/overcompensated

11. Mispositioned control rod(s)

   a. Misaligned rods
   b. Dropped rods
   c. Ejected rods
   d. Rod position indication failure
   e. Rod worth minimizer failure

12. Inability to drive one or more control rods

    a. Stuck rod or rods
    b. Malfunctioning control rod drives
    c. Control rod hydraulic flow control failure
    d. Uncoupled rods

13. Failure of emergency core cooling system (ECCS) components

    a. Passive systems failure--accumulators, core flood tanks, core fill tanks, core injection tanks, ice condenser
    b. Active system failure (includes both pump and valve failures)--core spray, high head injection, low head injection, ADS, containment spray, RWST/BWST

14. Fuel cladding failure or high activity in reactor coolant or offgas

15. Turbine faults

    a. Turbine trip
    b. Failure of turbine to trip
    c. Turbine runback / inadvertent power increase
    d. Eccentricity / vibration
    e. Stop, governor valve control failure

16. Failure of automatic reactivity control systems

    a. Control rods positive reactivity addition control failure
    b. Control rods negative reactivity addition control failure
    c. Inadvertent boration
    d. Inadvertent dilution
    e. Inadvertent cooldown / inadvertent reactor coolant pump start
    f. Inadvertent standby liquid control system (SLCS) actuation

17. Single/multiple steam generator tube leaks/ruptures

18. Secondary steam and water leaks

    a. Inside containment
    b. Outside containment
    c. Steam line break without isolation
    d. Water leaks - feedwater, AFW, SG blowdown

19. Failure of pressure/inventory control systems

    a. Solid plant--pressure increase exceeds limit
    b. Solid plant--power operated relief valve opened
    c. Pressurizer spray valve continuously open or closed
    d. Pressurizer heater control failure
    e. Pressurizer power-operated relief valve or safety valve open continuously

f. Pressure increase exceeds safety valve limit setting
g. Charging / letdown failures
h. MSIV closure - partial/full, single/multiple
i. Pressure regulator failure
j. Stuck open or inoperable bypass, vent safety, and relief valves
k. Feedwater control failure
l. EHC failures

20. Generator faults

a. Generator trips / full/partial load rejection
b. Generator failure to trip
c. Hydrogen control failure
d. Isophase cooling malfunction

21. Reactor trip/scram

a. Reactor trip/scram
b. Failure of reactor to trip/scram (auto and/or manual)
c. Scram accumulator malfunction

22. Loss of containment integrity - containment isolation system (CIS) failure

23. Radwaste system breach/failures

24. Loss of protective system channel

25. Non-nuclear instrumentation failures

a. Instrument failures
b. Interlock failures
c. Detector failures

26. Loss/malfunction of plant computer systems

27. Occurrence of valid/invalid alarms

28. Inadvertent ECCS, CIS actuation

APPENDIX D

SAMPLE: U.S. DEPARTMENT OF LABOR JOB ANALYSIS SCHEDULE FOR AUXILIARY CONTROL OPERATOR

U. S. Department of Labor
Manpower Administration

OMB 44-R0722

Estab. & Sched. No. ___ ________

JOB ANALYSIS SCHEDULE

1. Estab. Job Title AUXILIARY CONTROL OPERATOR
2. Ind. Assign. chem. (atomic energy)
3. S.I.C. Code(s) and Title(s) 2819 Inorganic Industrial Chemicals n.e.c. (1972 SIC same)

Code 509.182

WTA Group NA

DOT Title ____

Ind. Desig. ____

4. JOB SUMMARY:

5. WORK PERFORMED RATINGS:

Worker Functions

D (circled)	P	T (circled)
Data	People	Things
1	6	2

Work Field PROCESSING-COMPOUNDING Code 147

M.P.S.M.S. Metal, Ferrous and Nonferrous n.e.c. Code 539

6. WORKER TRAITS RATINGS

GED 1 2 3 (4) 5 6 R 4 M 3 L 3

SVP 1 2 3 4 5 (6) 7 8 9

Aptitudes G 2 V 2 N 2 S 2 P 3 Q 3 K 4 F 4 M 4 E 5 C 4

Temperaments D F I J (M) P R S (T) V

Interests (1a) 1b 2a (2b) 3a 3b 4a (4b) 5a (5b)

Phys. Demands (S) L M H V 2 3 (4) (5) (6)

Environ. Cond. (I) O B 2 3 4 5 6 7

7. General Education

a. Elementary 8 High School 4 Courses

b. College none Courses

8. Vocational Preparation

a. College none Courses

b. Vocational Education none Courses

c. Apprenticeship none

d. In-plant Training Radiation and Safety Training 1 month

e. On-the-job Training 18 months

f. Performance on Other Jobs 18-24 months as Utility Operator, Irradiated Fuel Handler, and Charge Operator

9. Experience 18-24 months combination experience as Utility Operator, Irradiated Fuel Handler, and Charge Operator

10. Orientation 4-8 hours

11. Licenses, etc. none - must be certified by company

12. Relation to Other Jobs and Workers

Promotion: From Charge Operator To Control Room Supervisor

Transfers: From none To none

Supervision Received: Control Room Supervisor

Supervision Given: none

13. Machines, Tools, Equipment, and Work Aids:
See Supplemental Sheet

14. Materials and Products:
See Supplemental Sheet

Supplemental Sheet

13. Machines, Tools, Equipment and Work Aids:

Machines

Nuclear Reactor: Mounted in concrete footing below ground level. Fifty feet long, fifty feet wide, and fifty feet high. The outer walls are made of concrete and steel and are six to eight feet thick. The reactor contains 1,003 control and safety rods, is fueled by enriched uranium fuel elements, is cooled by water, and a graphite moderator is located in the center of the core. It is a dual purpose reactor, producing plutonium and steam.

Nova Computer

Tools

none

Equipment

none

Work Aids

Procedures
Instrument dials
Instrument recorders
Temperature gages
Pressure gages
Flow gages
Level gages
Annunciator lights

14. Materials and Products:

Materials

Uranium fuel elements
Demineralized water
Helium gas

Products

Plutonium
Steam

17. General Comments: Vocational Education Courses

Worker is required to take on his own time, self study, college level courses in Reactor Physics, Heat Transfer, Fluid Flow, Emergency Procedures, Process Standards, Radiation Protection, Instrumentation and Control Systems, Reactor Operating Characteristics, and Fuel Handling and Core Parameters.

15. Job Definition:

Operates and controls helium atmosphere system in dual purpose nuclear reactor, producing plutonium and steam, using panel board console, and operates computer to solve operating problems in nuclear reactor plant: Adjusts controls on panel board to maintain specified levels of helium gas pressure and humidity in nuclear reactor and prevent corrosion on surface of reactor tubes. Selects and turns designated control buttons to maintain water flow and temperature in internal cooling loop of graphite shield, according to specifications. Adjusts blower fan controls and monitors reactor confinement system to insure that radioactive air is not blown into clean zones. Observes and interprets readings of instruments, such as temperature, pressure, and humidity indicators and recorders to detect variances in helium atmosphere operation and evaluate trends. Initiates corrective action, according to supervisor's instructions, own determination of trends, and reports from other system reactor controllers. Operates computer to obtain data to solve operating problems, such as variations in power level and tube flow, for supervisor and other control room operators. Records data to be used by professional and advisory staff for determination of immediate or future operational procedures. Participates in charge activities during nuclear maintenance shutdown.

---

16. Definition of Terms

none

17. General Comments : Four certified Nuclear Reactor Operators are required to control the operation of a dual purpose reactor. This worker rotates assignments with the Power Control Operator, BN Nuclear Control Operator, and AA Nuclear Control Operator, who are certified operators.

(cont'd Supplemental Sheet)

U.S. DEPARTMENT OF LABOR
MANPOWER ADMINISTRATION

Physical Demands and Environmental Conditions

ESTAB. JOB TITLE Auxiliary Control Operator ESTAB. & SCHED. NO.

DOT TITLE AND CODE 509.182

PHYSICAL DEMANDS		COMMENTS
1. STRENGTH		
a. Standing 50 %		
Walking 25 %		
Sitting 25 %		
	Weight	
b. Lifting NP		
Carrying NP		
Pushing NP		
Pulling NP		
2. CLIMBING	NP	
BALANCING	NP	
3. STOOPING	NP	
KNEELING	NP	
CROUCHING	NP	
CRAWLING	NP	
4. REACHING	F	4. Reaches for and handles dials, buttons, and switches on control panels, and computer controls.
HANDLING	F	
FINGERING	NP	
FEELING	NP	
5. TALKING		5. Talks and listens to other operators, supervisor, and auxiliary system personnel, regarding work problems.
Ordinary	F	
Other	NP	
HEARING		
Ordinary Conversation	F	
Other Sounds	NP	
6. SEEING		6. Near acuity required to read gages, dials, recorders, graphs, procedures, and computer printouts. Color vision needed to distinguish colored ink on charts and multi-colored lights on boards.
Acuity, Near	F	
Acuity, Far	NP	
Depth Perception	NP	
Accommodation	NP	
Color Vision	F	
Field of Vision	NP	

RATINGS: P. D.: (S) L M H VH 2 3 (4) (5) (6)

Analyst M. Weinberg Date 8/74 Estab. Reviewer ____

F.S. Reviewer A. Douglas Date 8/74 Title ____ Date ____

ENVIRONMENTAL CONDITIONS			COMMENTS
1.	ENVIRONMENT Inside 100 % Outside ____ %		
2.	EXTREME COLD WITH OR WITHOUT TEMPERATURE CHANGES	NP	
3.	EXTREME HEAT WITH OR WITHOUT TEMPERATURE CHANGES	NP	
4.	WET AND/OR HUMID	NP	
5.	NOISE Estimated maximum number of decibels	C 65 dbs.	
	VIBRATION	NP	
6.	HAZARDS		
	Mechanical	NP	
	Electrical	NP	
	Burns	NP	
	Explosives	NP	
	Radiant Energy	NP	
	Other	NP	
7.	ATMOSPHERIC CONDITIONS		
	Fumes	NP	
	Odors	NP	
	Dusts	NP	
	Mists	NP	
	Gases	NP	
	Poor Ventilation	NP	
	Other	NP	

RATINGS: E. C. : (I) O B 2 3 4 5 6 7

PROTECTIVE CLOTHING OR PERSONAL DEVICES

none

APPENDIX E

LICENSEE EVENT REPORTS INVOLVING PERSONNEL ERRORS RELATED TO LOCAL CONTROL STATIONS

APPENDIX E

LICENSEE EVENT REPORTS INVOLVING PERSONNEL ERRORS RELATED TO LOCAL CONTROL STATIONS

Licensee event reports (LERs) were examined for the period from June 1, 1981 to December 17, 1982. Twenty-four of the LERs involved personnel errors related to local control stations. Seventeen of these 24 LERs involved misalignment of valves caused by errors of maintenance or instrumentation-and-control technicians. These are listed in Table E.1. Seven of the LERs involved the misalignment of breakers or control switches. Table E.2 lists these.

TABLE E.1. Events Related to Valves

ACCESSION #	LER NUMBER	EVENT	PLANT	EVENT DATE	DOCKET/ (DATE)
0020180011	82-046	Equalizing valves left open on 3 steam generator flow transmitters	Summer 1	11/17/82	50-395 (12/16/82)
0020179601	82-021	Pressure switch isolated for turbine load reject relay	Quad Cities 2	01/15/82	50-265 (11/08/82)
0020177675	82-044	Pressure switch isolated for emergency diesel generator (EDG) jacket cooling water	Calvert Cliffs 2	09/15/82	50-318 (10/15/82)
0020177533	82-111	Pressure transmitter isolated from remote shutdown monitoring instrument	Sequoyah 1	09/03/82	50-372 (09/30/82)
0020175657	82-076	Differential pressure indicator isolated for steam generator	San Onofre 2	07/25/82	50-361 (08/24/82)
0020175639	82-005	Isolation valve partially closed for offgas stack sample line	Arnold	07/27/82	50-331 (08/05/82)
0020175578	82-049	Hi-flow trip transmitter isolated for main steam line "A"	La Salle 1	06/21/82	50-373 (07/20/82)
0020175573	82-008 Rev. 1	Cap missing on instrument test tee on reactor building penetration	Oconee 1	03/23/82	50-269 (07/23/82)
0020175566	82-016	Hi-flow trip transmitter isolated for main steam line "A"	Peach Bottom 2	07/09/82	50-277 (07/16/82)
0020175563	82-015	Hi-flow trip transmitter isolated for main steam line "B"	Peach Bottom 2	07/03/82	50-277 (07/16/82)
0020175232	82-053	Reactor water level-lo/high pressure core spray (HPCS) initiation switch isolated	La Salle 1	06/17/82	50-373 (07/14/82)
0020175218	82-052	Low pressure core spray (LPCS) discharge pressure hi/lo switch isolated	La Salle 1	06/20/82	50-373 (07/20/83)
0020175138	82-030	Stack gas sample valve line isolated	La Salle 1	05/31/82	50-373 (06/18/82)
0020174659	82-035	Sample line uncoupled on stack gas filter assembly	Dresden 2	06/01/81	50-237 (06/26/81)
0020172758	82-038 Rev. 1	Pressure switch isolated to turbine fast closure trip	Millstone 1	11/17/81	50-245 (01/13/82)
0020172753	82-002	Drywell pressure-hi switch isolated	Browns Ferry 1	01/06/82	50-259 (02/01/82)
0020172732	82-004	Differential pressure flow sensor isolated on auxiliary feed pump	Point Beach 1	02/06/82	50-266 (03-09/82)

TABLE E.2. Events Related to Breaker/Control Switches

0020179988	82-040	Vital bus distribution center circuit breaker opened when struck by conduit carried by contractor	Yankee Rowe	11/12/82	50-029 (12/10/82)
0020179674	82-068	DC feeder breaker tripped open by contractor causing reactor trip	Calvert Cliffs 1	11/09/82	50-317 (12/08/82)
0020176262	82-045	Breaker opened, possibly by being kicked, for MOV from service water to CCHX, resulting in loss of CCHX cooling water	Surry 2	07/28/82	50-281 (08/24/82)
0020176199	82-023	Main steam hi flow switches hit by removable handrail (due to contractor error) causing	Pilgram 1	08/13/82	50-293 (09/13/82)
0020175515	82-026	Three containment air radiation monitors inoperable due to control switches being left in "test" position by maintenance personnel	Millstone 2	06/23/82	50-332 (07/23/82)
0020175301	82-015	Breaker opened (assumed accidently knocked open) to safety injection system MOV valve, rendering system inoperable	Yankee Rowe	06/04/82	50-029 (07/02/82)
0020172991	82-001	Inverter output breaker to RHR system suction pressure transmitter opened when contractor dropped piece of sheet metal on it, causing it to fail high leading to autoclosure of suction valve and tripping of the running RHR pump	Zion 1	03/17/82	50-295 (03/25/82)

APPENDIX F

BLANK INTERVIEW GUIDE FOR PLANT VISITS

ID # ____________

Date ____________

Time ____________

LCS INTERVIEW GUIDE AND CHECKLIST

I. Initial Meeting Approach

Contact Name: ______________________________

Job Title/background: ______________________

Escort Name: _______________________________

Job Title/background: ______________________

II. Introduction:

____ Stress confidentiality (code #'s, sanitized photos)

____ Stress that our visit is not related to licensing

____ Stress research nature of our projects

____ Present 3 projects

Local Control Stations
NPP Maintainability Design Guidelines
Safety Systems Status Verification

III. Present Procedures

____ Visit target LCS's

____ Obtain objective environmental measures

Noise
Light
Humidity/Temperature

____ Photograph panels

____ Use checklists for presence/absence of environmental conditions and features

____ Ask questions about panel function and operation

____ Ask to see controls or displays of particular interest

ID #____________

Date____________

Time____________

VI. Estimate Time Requirements

____ 4-5 hr. total visit time

____ 20 minutes/LCS visited

V. Thank Plant and Individuals for their help

VI. Comments:

ID #____________

Date____________

Time____________

OPERATOR FAMILIARITY WITH LCS

What training have you received on the operation of this local control station? (Probes: Where are the emergency procedures located? Who else can help you operate? How will conditions change in an emergency?)

ID #____________

Date____________

Time____________

PANEL DESIGN

"What do you consider to be the three easiest systems to operate and why?"*

---

*This question was drawn from the BWR Owners Group Operator Survey (Reference 4).

ID #____________

Date____________

Time____________

PANEL DESIGN

"What do you consider to be the three most confusing or difficult systems to operate and why? Give an example of an incident in which there was difficulty in operating the system."*

*This question was drawn from the BWR Owners Group Operator Survey (Reference 4).

ID # ____________

Date____________

Time____________

ANNUNCIATOR WARNING SYSTEM

"Describe at least three features of your annunicator warning system that you feel have been most effective in helping you promptly identify a specific system performance problem."

ID #____________

Date____________

Time____________

ANNUNCIATOR WARNING SYSTEM

"Describe at least three features of your annunciator warning system that you feel have resulted in inefficient or erroneous fault isolation."

ID #____________

Date____________

Time____________

PANEL DESIGN

"Describe any changes to the local control station that you feel would improve the operator's capability to recognize and control normal and abnormal plant operating conditions."

ID #______________

Date______________

Time______________

WORKSPACE LAYOUT AND ENVIRONMENT

"Describe at least three aspects of the local control station workspace, furniture, equipment layout, or environmental conditions that you find very useful or positive. Describe specific incidents or ways in which these have been helpful to effective job performance."

ID #____________

Date____________

Time____________

WORKSPACE LAYOUT AND ENVIRONMENT

"Describe at least three aspects of the workspace, furniture, equipment layout, or environmental conditions that you find particularly bothersome. Describe specific incidents or ways in which these have been ineffective and have interfered with job performance."

ID #____________

Date____________

Time____________

COMMUNICATIONS

"Describe at least three characteristics of the local control station communications systems that you find most effective in providing you timely, intelligible contact with other personnel."

ID #____________

Date____________

Time____________

COMMUNICATIONS

"Describe any problems with the local control station communications systems (phones, page phones, loudspeakers, radios, etc.) that have prevented or interfered with your ability to communicate with other personnel. Consider, for example, delays, interference."

ID #____________

Date____________

Time____________

PANEL DESIGN

"Can you think of any occurrences when an operator activated the wrong control, activated a control inadvertently, or activated a control incorrectly? (Probes: Why did this happen? What system and panel were involved? How and when was the mistake discovered? What was the consequence? Have there been other such occurrences? If so, describe. What would you recommend to prevent a recurrence of any of these problems?)"

Photograph any control that was inadvertently activated and check items below:

____ Traffic area?

____ Room for people or objects to pass?

____ Do people passing carry things or wear heavy clothes?

____ Would shielding help?

____ Is control relocation feasible?

ID # ____________

Date ____________

Time ____________

OPERATOR COMFORT

What design features are provided for local control stations operator comfort?

Seating?

Adjustments?

Backrests?

Workspace Layout?

Arm, leg, head room?

Tilted displays?

Facilities?

Environmental condition controls

Noise abatement?

Lighting?

Temperature improvement?

APPENDIX G

CHECK LIST FOR ENVIRONMENTAL MEASUREMENTS

ID # ____________

Date ____________

Time ____________

LOCAL STATION CONTROL ROOM LAYOUT DRAWING

Note in diagram where measurements taken:

N=Noise   L=Lighting   T=Temperature/humidity   V=Air Velocity

What changes in environmental conditions are anticipated during an emergency event? ____

____

____

____

General comments? ____

____

____

ID #____________

Date____________

Time____________

LIGHTING SURVEY

Measurements made by:____________________________

Equipment/instrument used:_______________________

Serial #__________________ Calibration date:____________________

Location	Description (be specific)	Meter Reading	
		Normal	Emergency
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			

ID #____________

Date____________

Time____________

SOUND SURVEY RECORD

Measurements made by:__________________________

Equipment/instrument used:______________________

Serial #_________________ Calibration date:__________________

Location	dB(A)	Octave Band Center Frequency					Remarks/Conditions
		250	500	1K	2K	4K	

Take measurements at center of each panel or console and at all locations requiring communication with the primary operating area, with alarms and without alarms.

ID #____________

Date____________

Time________ ____

HUMIDITY/TEMPERATURE RECORD

Measurement made by:____________________________

Equipment/instrument used:______________________

Serial #:________________

Dry bulb temp:______________ Wet bulb temp:_______________

Calculated temperature:___________________

Calculated humidity:______________________

AIR VELOCITY

At 4 ft. height:

none____ slight____ moderate____ substantial____ severe____

At 6 ft. height:

none____ slight____ moderate____ substantial____ severe____

APPENDIX H

ENVIRONMENTAL CONDITIONS AND HUMAN PERFORMANCE

APPENDIX H

ENVIRONMENTAL CONDITIONS AND HUMAN PERFORMANCE

This study addressed the environmental condition at local control stations because adverse conditions have the potential to degrade the performance of the operators. If the local control station being used is important to reactor safety systems, the effect of environmental conditions on operator performance may be critical to plant and public safety.

Section 4.2 of this report presents the environmental data for air temperature, air velocity, humidity, illumination, and noise levels at some local control stations in several power plants. This discussion provides some background about how temperature, illumination, and noise affect human performance.

TEMPERATURE REGULATION

Man's ability to regulate body temperature is dependent upon a complex balance between heat gain and heat loss. Heat gain by the body can result from radiation, convection, production of body heat during muscular activity and basal metabolic activity. At the same time heat loss is constantly occurring through radiation, convection and evaporation. This heat balance is usually expressed in the following form:

$$M \pm R \pm C - E = 0$$

where M represents the metabolic heat gain, R represents heat exchange due to radiation, C represents heat exchange through convection, and E is heat loss due to evaporation. In this relationship the amount of heat loss or gain due to conduction is considered negligible, and the body is considered to be in a state of thermal balance. The mechanisms involved in this balance serve to maintain the body core temperature within a narrow range, approximately 36.1 to 37.2°C. Variations to either temperature extreme can result in discomfort, job performance reduction, damage to body structures and processes, and under extreme conditions, death.

Body surface temperature, on the other hand, can vary considerably without serious consequences. The temperature differential at rest between the body core and surface is typically 4°C and may increase to as much as 20°C without resultant damage. The role of temperature control is the regulation of these temperature differentials or the balance between overcooling and overheating (Astrand 1977).

In an attempt to maintain the heat balance and constant core temperatures, the regulating mechanism must work within its capacity and heat gains and losses must not be excessive (Murrell p. 261).

In nuclear power plant (NPP) local control stations it is assumed that temperature extremes are more likely to occur at the high end of the scale rather than at the low end. In this situation the temperature regulating mechanisms work to maintain a constant core temperature while dissipating heat. An increase in heat loss can be achieved through shunting blood, which has a high heat capacity, to the peripheral circulation (vasodilation). This results in an increased skin temperature which in turn results in higher heat conductance. Other important regulating mechanisms which are activated at increased temperatures include evaporative heat loss and increased respiratory rate. These mechanisms serve to cool the skin and blood circulating to the pheriphery and to increase the saturation of air with water vapor, respectively.

If heat gain is extreme and the body core temperature increases, several consequences can result. Heat stress can result in initial discomfort, and can lead to performance degradation, faintness, loss of consciousness and, under extreme conditions, death. It is, therefore, important to provide an environment where the temperature favorably influences the efficiency and safety of the personnel performing critical plant functions.

The external factors that affect the body's ability to regulate core temperature include air temperature, air humidity, and air velocity. Air temperature affects convective heat exchange and is easily measured using a mercury thermometer. Relative humidity, which affects the rate of evaporation, can be measured using a sling psychrometer or determined using psychrometric charts when dry-bulb and wet-bulb temperatures are known. Air velocity, which can affect both convective heat exchange and evaporative heat loss, is measured using an anemometer. Because these factors interact to affect temperature regulation, several scales have been developed to integrate these factors into one measurement or index. The effective temperature index is the most widely accepted scale to date.

There are two acceptable effective temperature (ET) scales in use today, both of which were developed under the sponsorship of the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE). The original ET scale, which was applicable to a sedentary person, has been shown to overemphasize the effects of humidity under cool conditions and underestimate the effects of humidity in warm environments. In addition, air movement was not fully accounted for in hot and humid conditions. Therefore, a new effective temperature scale was developed, based in part on heat regulation physiology (McCormick, 1976). This new effective temperature scale is illustrated in Figure H.1. Each ET line represents combinations of dry-bulb temperature and relative humidity that would produce approximately the same skin "wettedness" from regulatory heat loss due to sweating. At a dry-bulb temperature of about 77^{o}F and a relative humidity of about 50%, the body is said to be in a state of thermal neutrality with respect to heat loss due to vaporized sweating. Higher or lower temperatures at this relative humidity would change the evaporative heat loss of skin "wettedness." The ET scale is based on these ratios, which are shown at the 5% relative humidity level. Additional ET lines represent other levels of skin "wettedness" that are due to associated combinations of dry-bulb temperatures and relative humidities. The ET lines also reflect approximate comfort zones or different levels of thermal sensation. The comfort zone is shown to span ET values of approximately 74 to 81. This zone is bordered by slightly cold and slightly warm zones, with uncomfortably cool, uncomfortably warm and intolerable zones also included (McCormick, 1976). The comfort zone illustrated here is represented by equivalent dry-bulb temperatures that are slightly higher than those for the comfort zone shown in Figure H.2 and used in NUREG-0700. The new effective temperature scale reflects the in-

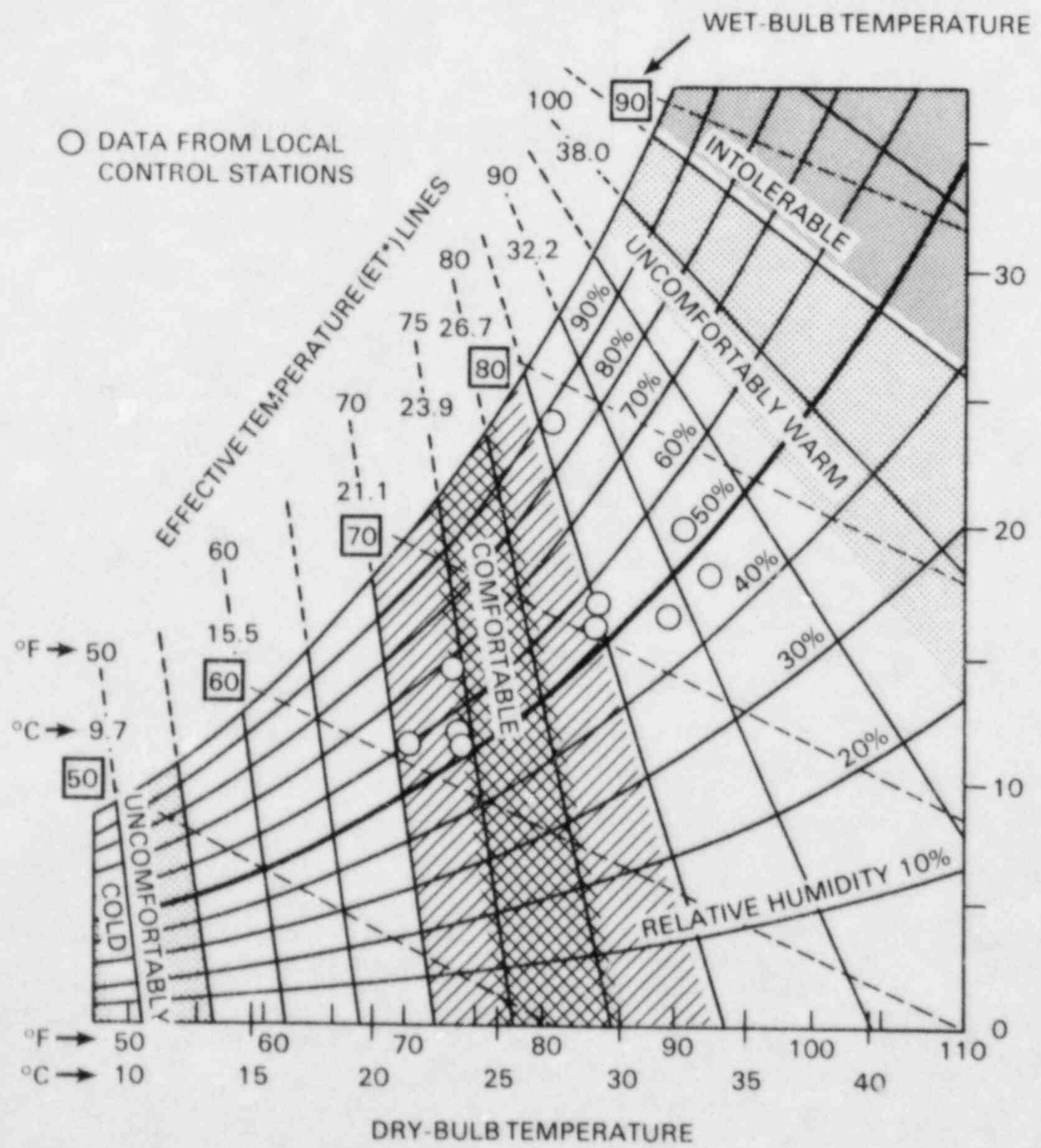
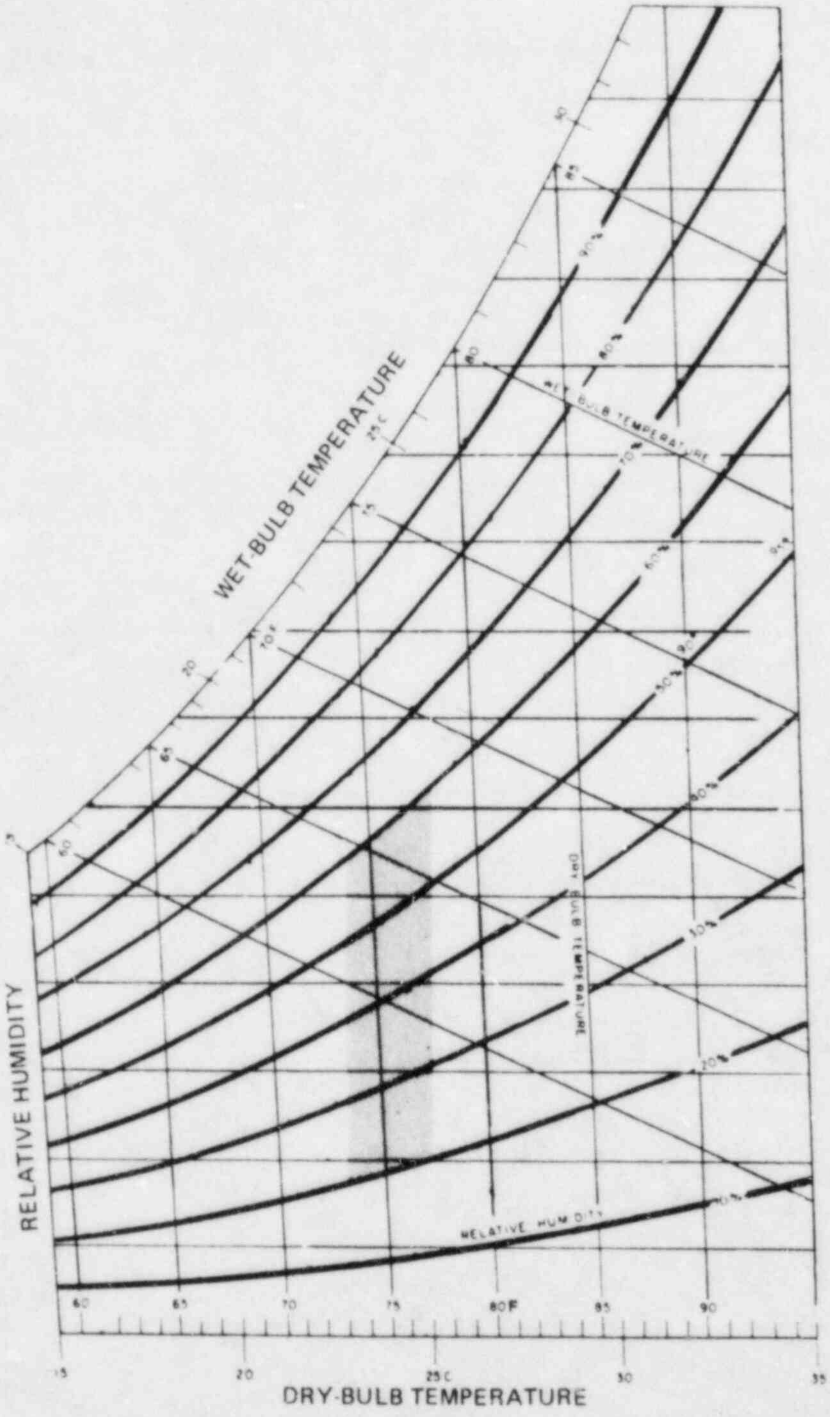


FIGURE H.1. Effective Temperature Scale with LCS Data



Ashrae comfort standard 55-74

*The envelope applies for lightly clothed, sedentary individuals in spaces with low air movement (less than 45 FPM)

FIGURE H.2. Effective Temperature Scale and Comfort Zone as Shown in NUREG-0700 creased comfort at decreased relative humidities which results in a comfort zone spanning different dry-bulb temperatures at varying relative humidities. It should be noted, however, that the comfort zone in Figure H.2 includes upper and lower relative humidity bounds which are not included in the new effective temperature scale.

ILLUMINATION

A good interior lighting installation will have the following characteristics:

1. The illumination is sufficient to enable one to accomplish the seeing task satisfactorily.

2. The distribution of the illumination is uniform throughout the seeing area.

3. The light is properly directed and diffused by the fixtures and by proper painting of the surroundings.

4. The fixtures shield the light source so that a brightness near the horizontal (to at least 30^{o}below) is low (1/2 candle per square inch for large fixtures to 2 for small ones).

5. Shadows, although important in providing form and depth to objects, are soft.

6. The color of the light source and that of the wall paint is acceptable to the type of service and the preference of the individuals involved.

7. Glare is entirely eliminated.

8. Contrasts in brightness are not too great, as they may be the cause of glare and visual discomfort (Eshbach, 1975).

There should be an attempt to minimize illumination problems associated with illumination quality as well as quantity. Because the contrast, size of the object viewed and amount of viewing time are often inherent in the task, typically the amount of illumination is increased. However, this is not always cost effective and can produce glare and fatigue (Konz, 1979). Examples of recommended levels of illumination are included in Table H.1.

The quality of light is determined by the distribution of brightness and can be enhanced by controlling such things as contrast, glare and orientation. To detect shapes, it is possible to maximize the contrast between the target or task and its background. On the other hand, to detect surface characteristics like color and texture, one should minimize the contrast. In addition, constant adjustments that must be made when alternately viewing bright and dim areas should be minimized to decrease fatigue. Glare, which is categorized into direct and indirect glare, can be considered to be any brightness which results in discomfort, visual interference or eye fatigue. Sensitivity to glare increases with age and is more pronounced in individuals with blue eyes. Direct glare is a result of a light source within the field of view, whereas indirect glare is caused by a light source reflected from a surface. Both types of glare can be controlled by masking, filtering, redirecting light sources, etc. The proper orientation of lights can be used effectively to sharpen or blur an image and to reduce glare (Konz, 1979).

TABLE H.1. Recommended Levels of Illumination (NUREG-0700)

Work Area or Type of Task	Task Illuminance, footcandles		
	Minimum	Recommended	Maximum
Panels, primary operating area	20	30	50
Auxiliary panels	20	30	50
Scale indicator readi[illegible]	20	30	50
Seated operator stations	50	75	100
Reading:			
• Handwritten (pencil)	50	75	100
• Printed or typed	20	30	50
Writing and data recording	50	75	100
Maintenance and wiring areas	20	30	50
Emergency operating lighting	10	As above for area/task	

NOISE AND PERFORMANCE

Humans can perceive sounds over a wide range, usually between 2 Hz and 20 kHz, and are most sensitive to a middle range of approximately 0.5 kHz and 3 kHz. In a working environment, sounds that are considered "unwanted" or disturbing, whether normal or otherwise, are usually described as noise. Control of noise at lower levels [55 to 80 dB(A)] serves primarily to eliminate annoyance, whereas noise control at levels exceeding 90 dB(A) serves to protect the hearing of personnel (Konz 1979).

The Occupational Safety and Health Administration (OSHA) has established recommended levels of noise exposure for specific durations in industry jobs (McCormick 1976). This information is presented in Table H.2. If the noise is intermittent, tolerance limits are a function of the intensity and the durations of exposure and nonexposure. This relationship is presented in Figure H.3.

TABLE H.2. Permissible Noise Exposure for Industry Jobs (Federal Register 1971)

Duration Per Day (hours)	Sound Level (dB-A)
8	90
6	92
4	95
3	97
2	100
1 1/2	102
1	105
1/2	110
1/4 or less	115

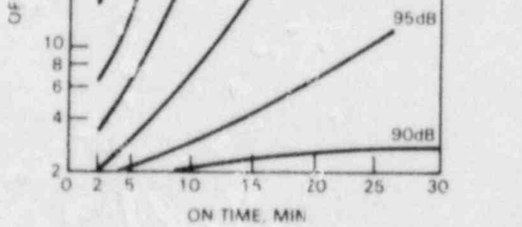


FIGURE H.3. Guide to Allowable Exposure Times for Intermittent Noise

Although it is difficult to make the generalization that noise causes a degradation in task performance, there is evidence that certain tasks are affected by noise. Among these are certain mental tasks; tasks requiring skill and speed (Roth, 1968); and tasks requiring high levels of perceptual capability (Boggs and Simon, 1968). In addition, there is evidence to suggest that sensory overload, where noise stimuli exceed the individual's information-handling capacity, can cause degradation in task performance (Finkleman and Glass, 1970).

At local control stations one might expect noise to be of the continuous or intermittent type which would cause annoyance or mask communication information vital to completing critical plant functions. Noise can require personnel to increase their concentration, can cause a reduced level of comfort, and consequently increase fatigue (Konz, 1979). Noise which masks communication between two points is of critical concern. Figure H.4 illustrates voice levels required under specified ambient noise levels and speaker to listener distance in a control room atmosphere. Upper limits on background noise for this environment have been put at 65 dB(A).

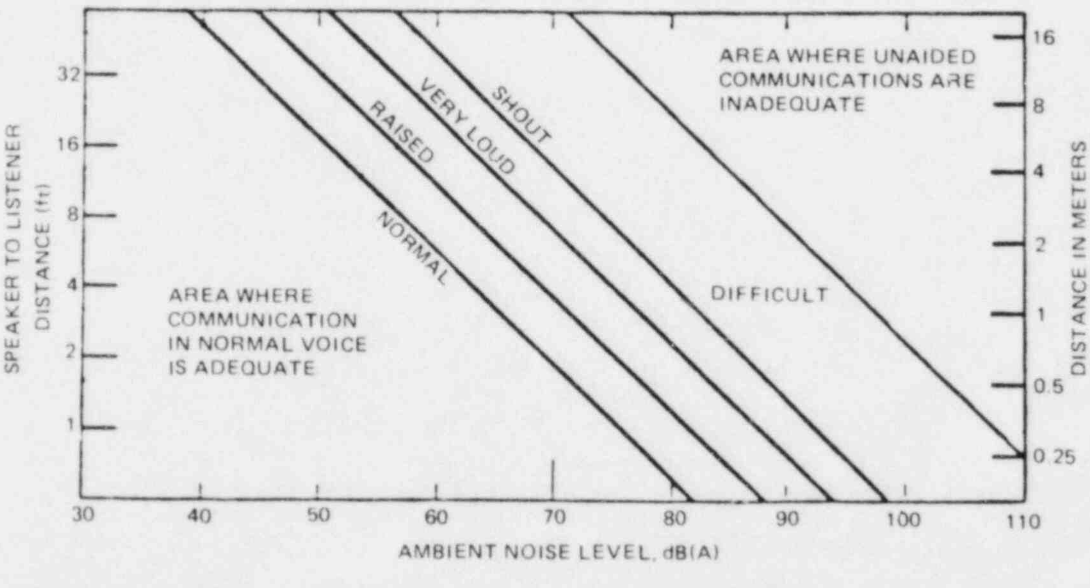


FIGURE H.4. Voice Level as a Function of Distance Between Speaker and Listener and Ambient Noise Level

Although hearing loss can be caused by high noise environments, it is assumed that local control stations are not located in areas where noise continuously exceeds 90 dB(A), and are not used frequently enough to contribute significantly to these losses.

The A scale is an acceptable standard for reporting noise in decibels, reported as dB(A). This allows noise level to be reported as a single number rather than many levels at corresponding frequences. The A scale (corresponding to a 40-phon equal-loudness curve) was devised to simulate hearing response at normal noise conditions and therefore, the weightings applied tend to attenuate the lower frequencies.

APPENDIX H - REFERENCES

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16. ABSTRACT (200 words or less)
The Pacific Northwest Laboratory has completed a project to identify human factors deficiencies in safety-significant control stations outside the control room of a nuclear power plant and to determine whether NUREG-0700, "Guidelines for Control Room Design Reviews," would be sufficient for reviewing those local control stations (LCSs). The project accomplished this task by first, reviewing existing data pertaining to human factors deficiencies in LCSs involved in significant safety actions; second, surveying LCSs environments and design features at several operating nuclear power plants; and third, assessing the results of that survey relative to the contents of NUREG-0700. The study's conclusions are 1) a definitive list of safety-significant local control stations cannot be specified because power plant designs vary significantly; 2) most, if not all, local control stations have design deficiencies that could be corrected by applying human factors engineering principles; and 3) NUREG-0700 is generally applicable to LCSs but that guidance is needed to address the design of manually operated valves and the design requirements of LCSs in extreme environmental conditions. Finally, the study recommends an approach for improving present LCSs to reduce the likelihood that operator error will occur.

17. KEY WORDS AND DOCUMENT ANALYSIS

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