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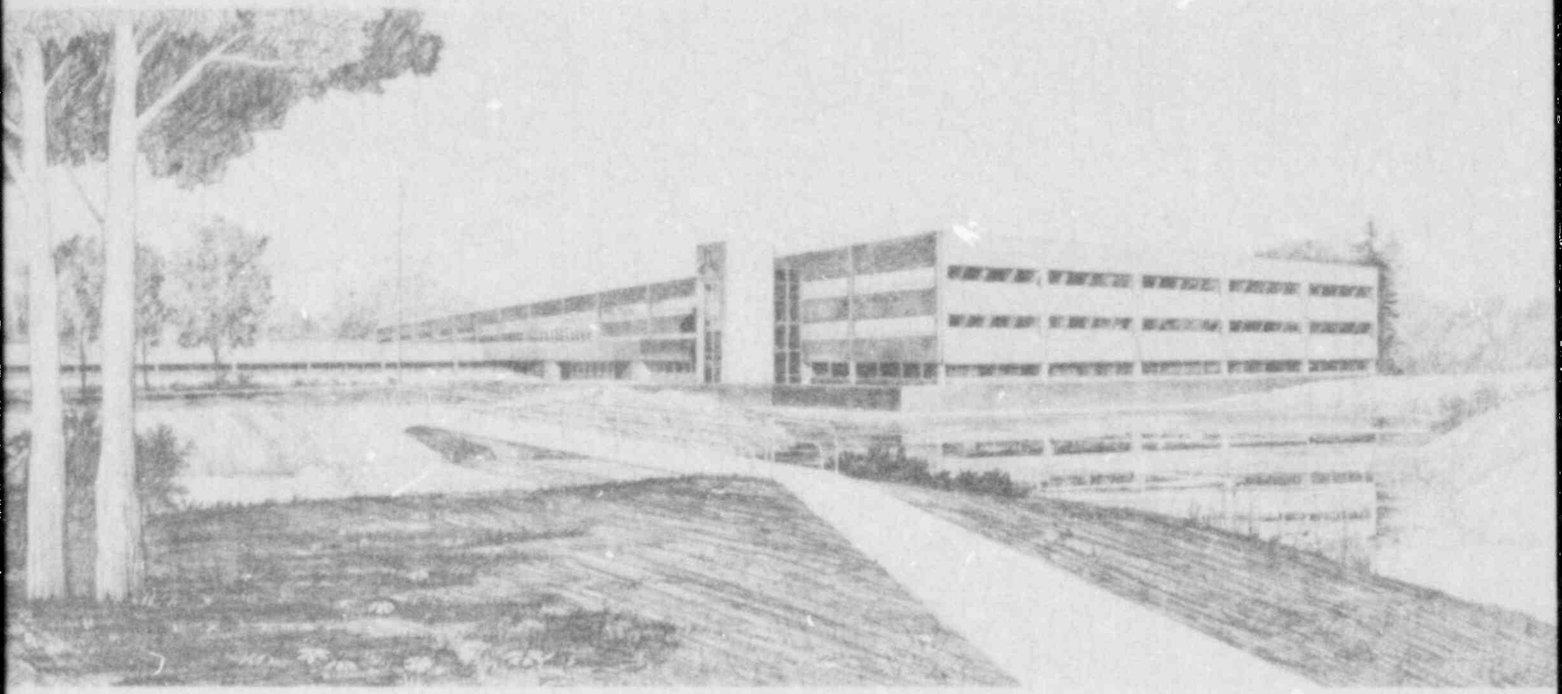

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Nuclear Control Room Modifications and the Role of Transfer of Training Principles: a Review of Issues and Research

Charles R. Sawyer
Richard F. Pain
Harold Van Cott
William W. Banks

August 1982

Prepared for the
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NUCLEAR CONTROL ROOM MODIFICATIONS AND THE ROLE OF TRANSFER OF TRAINING PRINCIPLES: A REVIEW OF ISSUES AND RESEARCH

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ABSTRACT

This report addresses issues and research related to the implementation of NUREG-0700 . . . specifically, transfer of training considerations associated with control room modifications, retrofits, and general upgrades. The ultimate purpose of this effort is to identify literature and data which would indicate any specific negative effects of instrumentation and control board changes on operator performance, especially under high stress conditions. An exhaustive search for these types of applied technical studies failed to reveal anything substantive due to the lack of definitive applied work in this area. However, a successful review of the theoretical and human performance literature was completed with emphasis placed upon the generalizability of transfer of training studies to control room modification scenarios. Based upon the studies reviewed and many years of experience relative to retrofit activities, the conclusions drawn in this report are:

1. There is no evidence to predispose one to presume that the *judicious and systematic* application of human factors engineering design criteria would degrade operator performance in nuclear control rooms—either short- or long-term.
2. There is ample evidence that the application of human engineering design criteria will enhance operational effectiveness, increase system safety, and allow operators greater ease and efficiency in system control and information extraction.
3. Several studies also pointed out that close adherence to human engineering design criteria during control room retrofit will create a greater degree of acceptance by operators and plant managers to these changes.
4. There is evidence to indicate that some design changes, if not thoroughly examined and analyzed, could lead to negative transfer of training effects for operators.

Several research approaches and discussions which would increase our understanding of the impact negative transfer of training may have upon recently modified (retrofitted) systems are outlined in the summary. The lessons learned from such studies would, in our estimation, have substantive implications from a plant design and human performance perspective.

FIN No. A6108 Augmented Operator Capability

ACKNOWLEDGMENTS

The initial planning and technical preparation for this project were performed at INEL, EG&G by Ms. Catherine Stewart. Her Interim Report, EGG-SSCC-5644, November 1981, *Reactor Operator Adaptation to Design Change*, set the stage for the work reported herein.

CONTENTS

EXECUTIVE SUMMARY

The Problem

Within recent years it has become increasingly apparent that human error affects plant safety and that many human errors are induced by the failure of control room design to conform to established human factors standards and criteria. As a result, utilities have added new instruments and controls voluntarily and in compliance with NRC requests, and even more extensive modifications can be expected as detailed control room human factors design reviews are undertaken.

Changing a control room to conform to good human engineering practice, while important, is not the only step in achieving improved performance or reduced operator error. Modifications to control rooms must be examined and considered in relation to existing patterns of learned crew behavior.

Crews will readily adapt to or learn to use many control room additions and modifications. In other words, there is a positive transfer of training from the original design to the modified design. However, there is a possibility that some changes, though they conform to good human engineering standards, promote negative transfer of training. That is, the habits and patterns crews used before the modification interfere with learning and use of the changed controls, displays, or procedures. In every case modifications must be examined to assess whether or not they will disrupt or facilitate the process of transfer from the old to the new control room situation.

Purpose

The goal of this project was to survey applied and theoretical studies dealing with the effect of control room change on operator performance under high stress conditions. Our survey did not find any directly applicable applied studies, hence our attention centered on the theoretical literature dealing with transfer of training. These findings were then used to develop a series of examples which illustrate the kinds of modifications that enhance control room performance and those that detract from it.

Transfer of Training Research Findings

The majority of transfer research has been conducted in college and university laboratory settings and reveals the basic conditions, operations, and processes which influence the direction and extent of transfer of training. Such research has dealt primarily with such variables as stimulus and response similarity, stimulus predifferentiation, response difficulty, amount of practice, and conceptual task simularity; in addition, such secondary variables as warm-up and amount of practice have been studied.

Substantial research also has been conducted on transfer of training from dynamic and procedural simulators (e.g., cockpit simulators) to operational equipment and systems (e.g., actual aircraft). The degree of simulation fidelity required for positive transfer depends greatly on the type of task being trained. For example, procedural tasks are as effectively trained on low fidelity as high fidelity simulators.

Based on the reviews of basic and applied literature summarizing principles describing positive and negative transfer, effects are presented in Table ES-1.

Implications for Control Room Modifications

While the principles discovered in laboratory and simulation settings have been shown to be applicable to a wide range of real world settings, there are difficulties in directly applying them to new areas such as nuclear power plant control rooms. The major problem in a complex operational environment is defining the actual stimulus and response. Since no transfer research has been conducted in the area of control room operations, the effects of large-scale changes (e.g., major control board and procedural modifications) upon operator performance are difficult to predict. However, fairly modest and straightforward control/display enhancements and backfits are

Table ES-1. Basic principles of the transfer effect

Primary Principles

1a. Negative transfer will be produced when responses which conflict with the original ones are introduced in the modified design.

1b. A possible exception to this principle is the case where pre-modification controls and displays either conflict with population stereotypes or are not designed consistently. In such cases, negative transfer may already exist and can be eliminated only through modification.

2. Positive Transfer usually will occur when responses are unchanged, even when substantial stimulus changes are made.

3. The greatest amounts of positive transfer are generally produced by maintaining the conceptual similarity of the original and modified tasks.

Mediating Principles (Technical Title in Parentheses)

4. There is a continuum of similarity/difference for stimuli and responses. The amount of positive or negative transfer varies depending where the new (post-change) stimulus or response falls on that continuum (see Figure 1). (Stimulus/response similarity gradient)

5. Any time operators understand how stimuli and responses relate to subsystem operation, i.e., the value or function of the information displayed or control moved, positive transfer will be enhanced. (Mediation)

6. Learning or practice under varied stimulus or task conditions will enhance positive transfer. (Stimulus generalization)

7. If the stimulus and response tasks are thoroughly learned prior to any control-display (C-D) changes, this will facilitate either relearning and/or positive transfer after C-D modification. (Original learning effects)

8. When verbal cues or names can be associated with the C-D changes and learned by operators, positive transfer will be enhanced. (Predifferentiation)

another matter. Both controls and displays have definable stimulus and response characteristics. Some of the stimulus components are position, shape, size, color, information, informational change, and spatial relationships. Response components include identification, reading, direction of movement, discrimination, and sequential readings and control movements. In adding enhancements or making design changes, negative transfer may be produced if the modifications are not carried out with reasonable care. Basically, the introduction of behavioral requirements which conflict with the old ones can lead to interference from the originally learned behaviors. The consequence is operator error of one type or another such as misidentification, incorrect sequence reading or controlling, misreading, etc.

Modest changes in controls and displays can be achieved with minimum likelihood of errors due to negative transfer. Granted that there may on occasion be temporary decrements in the performance of experienced operators, these should rapidly wash out with a minimum of retraining on the changes. In addition, changes may in fact eliminate a great deal of negative transfer already existing in the control room due to inconsistencies or conflicts with population stereotypes. Finally, in the present study a number of examples (see Figure ES-1) were created to illustrate ways in which negative transfer can be produced or avoided in modifying instrumentation. The illustrations are important because they show in a concrete manner the way in which simple redesign and enhancement mistakes (e.g., control-display reversal, sequential change, etc.) can greatly increase the probability of operator error due to negative transfer.

Summary and Discussion

Historically, transfer of training has been of interest in both academic and applied-learning settings. While earlier views often held that rigorous training in repetitive tasks strengthens or develops one's memory in some fashion, somewhat different views prevail today. In general, two fundamental categories of transfer phenomena are widely recognized: specific and nonspecific transfer. Specific transfer refers to those phenomena which are related to the physical or procedural commonality of two tasks. Nonspecific transfer encompasses a number of cognitive processes and warm-up effects. Different experimental paradigms have been developed both to separate the effects of specific and nonspecific phenomena and to provide a tool for the evaluation of the learning processes which underlie both positive and negative transfer.

In the area of theoretical research a great number of operational approaches have been employed in the study of transfer. Among the more interesting variables which have been studied are stimulus-response similarity, predifferentiation of stimuli, response difficulty, amount of practice, and conceptual task similarity. Such variables as stress, task variety, and warm-up also have been employed in transfer research. Among the conclusions which apply to positive and negative transfer, a few are particularly deserving of mention. In respect to negative transfer, changing the pre- and post-task responses seems to have the greatest decremental effect upon second-task performance, although concurrent changes in stimulus similarity can reduce negative transfer. On the other hand, decreases only in stimulus similarity, at least up to a point, often produce little reduction in positive transfer and no negative transfer. On the positive transfer side, it appears that a number of variables and learning phenomena contribute to transfer of training. Response learning, stimulus discrimination, and large amounts of first- or second-task practice all appear to increase positive transfer and/or eliminate negative transfer. With sufficient first- or second-task practice, for example, any interference from the initial task seems to virtually disappear. Also, the conceptual relationship between tasks seems to be critical, and positive transfer often is found in situations where the original and transfer task are physically quite dissimilar. Finally, there seems to be little evidence regarding the influence of stress on transfer performance.

In regard to the human performance research, the data generally support the above conclusions, although the amount of experimental manipulation has been much more limited. Motor skills research indicates that when response (control) characteristics are changed substantially, negative transfer is likely. Simulation research reinforces the notion that cognitive aspects or original learning may be of equal or greater importance in transfer performance than are physical characteristics. Even paper-and-pencil simulation, for example, can produce substantial positive transfer in some training situations (e.g., aviation).

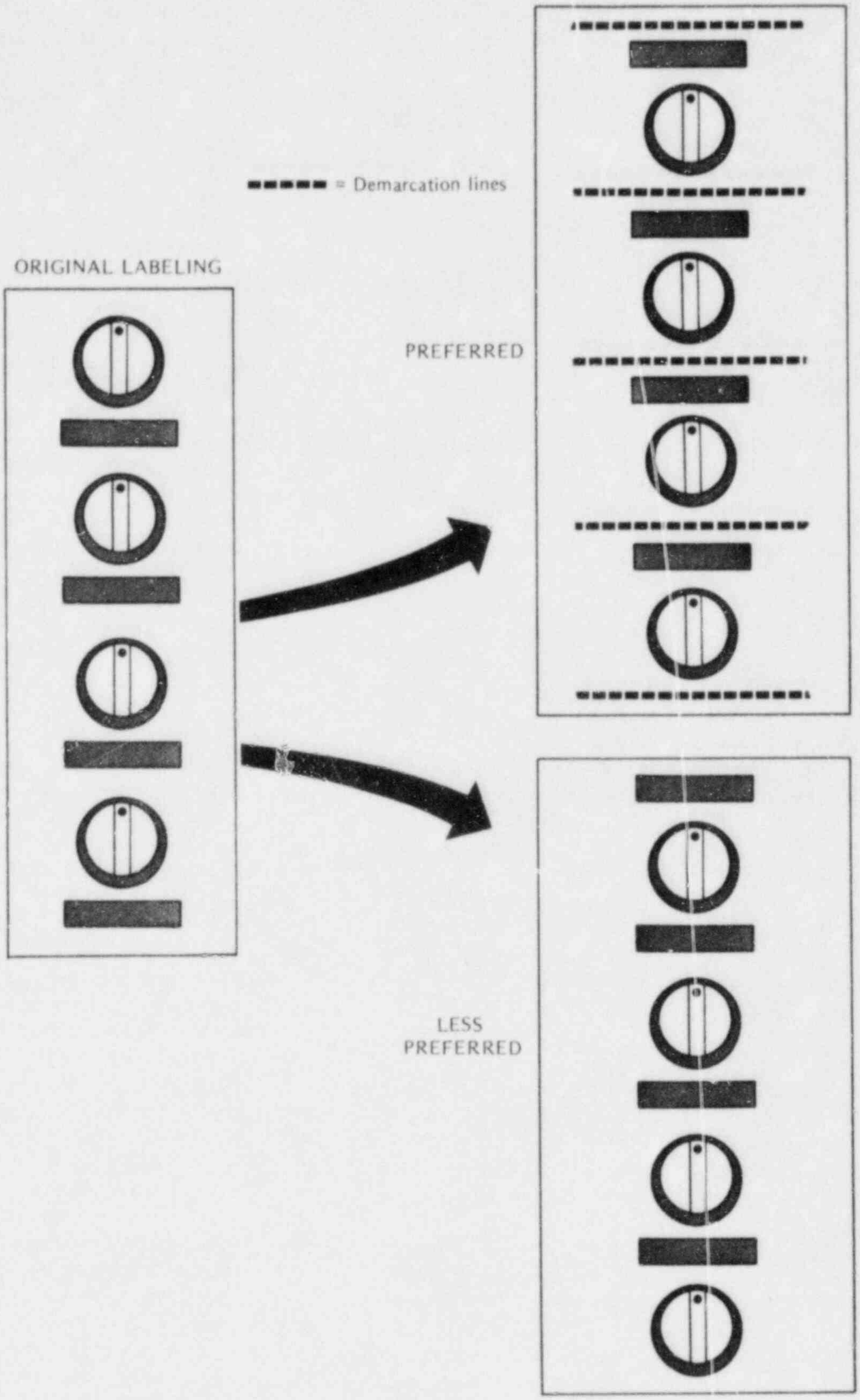


Figure ES-1. Examples illustrating ways in which negative transfer can be produced or avoided in modifying instrumentation.

Further Research is Necessary. In respect to the question of system modification and transfer, some caution is necessary. Although some of the motor skill work shows that control reversals and partial reversals will produce negative transfer, little apparent research has been done in situations where substantial system modification has been done. Nonetheless, it would appear that the principles abstracted from the transfer literature should be applicable to the redesign situation as well. The problem is not that of identifying new principles but one of identifying the stimuli and response characteristics of tasks which are to be modified. For example, given the complexity of NPP control rooms, one can ask the question, "What does and does not constitute change from the perspective of the operator?"

To address this and a variety of other issues, a matrix is shown in Figure 21 on page 59. The rows and columns, respectively, represent the basic types of procedural and display/control changes possible, while the variables listed below the exhibit represent numerous task and plant factors which could be studied in conjunction with such changes. Using the matrix and the list, a great number of fairly simple research projects or experiments could be generated. The next step is to select those research projects that will quickly and efficiently address the basic question: Do the transfer principles apply to NPP control room changes? Some basic types of applicable experiments addressing such questions and requiring minimal resources immediately come to mind. A series of small-scale experiments using low-fidelity simulation (cardboard mock-ups with drawings or photos of several panels from an NPP control room) that systematically vary task characteristics could be attempted in examining negative and positive transfer effects. Also, using the same simulation equipment, task complexity could be varied for selected cells from the matrix (three levels of complexity, e.g., one display-control link; one panel; one system). If negative transfer effects are produced, variation in response similarity (particularly full and partial mirror imaging conditions) would help to define fundamental conditions of negative transfer. Also, research on varying training conditions would help to define the training necessary to act as a countermeasure.

NUCLEAR CONTROL ROOM MODIFICATIONS AND THE ROLE OF TRANSFER OF TRAINING PRINCIPLES: A REVIEW OF ISSUES AND RESEARCH

INTRODUCTION

Background

The life cycle of a nuclear power plant is approximately 40 years. During the plant's life cycle numerous modifications are usually made, particularly in the control room. It has been found that extensive changes had often been made in control rooms after only a few years of plant operation.[1] Within recent years, control room modification has accelerated as utilities have added new instruments and controls voluntarily or in compliance with NRC requests. Even more extensive modifications can be expected to occur within the next few years as utilities undertake detailed control room human factors design reviews of the type outlined in NRC NUREG-0700 and NUREG-0801.

NRC's rationale for calling for control room reviews is based on the argument that human error is a major factor in plant safety. Many human errors are caused by or related to poor human factors design and poor control room layout. If existing control rooms are retrofitted to eliminate human engineering discrepancies (HEDs), the probability of human error and plant risk will decrease. There is abundant evidence and years of experience to support this position; most human errors in complex man-machine systems can be traced to deficiencies in human factors engineering (HFE) rather than to willful mischief or random human error. A carefully planned program of control room modifications can be expected to reduce the probability of human error and plant risk. These control room modifications would be accompanied by gains in objectively measurable parameters of plant performance such as availability and near-miss incidences.

Despite the potential benefits of a well-planned and carefully implemented program of control room human engineering improvements, potential liabilities may exist. These liabilities are attributed to the costs associated with these engineering modifications and to potential disruptive effects on operator performance (i.e., such as increased errors resulting from shifting from a familiar, premodification control room to one that has been changed and in some respects may be unfamiliar).

The costs of control room modifications can be substantial. Estimates for a surface enhancement program (simple improvements such as adding or changing paint and tape, or using better labels) may range from 100 to $300K. A program that entails the relocation or replacement of instruments, controls, or annunciators may run as high as $1 million (NRC Advisory Committee on Reactor Safeguards, transcript of the January 5, 1982, meeting of the Subcommittee on Human Factors). As control room modifications are made, procedures and other documentation must also be changed concurrently. Changes in the plant simulator also will almost certainly be required. These changes will increase the total cost.

These potential, although temporary, disruptive effects of control room changes on operator performance are more difficult to assess than the cost of those changes. Some industry opponents of control room change have seized upon the possible negative aspects of control room change on operator performance to argue against making any changes at all. For the most part, those who take this position are persons who have heard of the concept of "negative transfer of training," but have little understanding of the theory or research related to it. A negative transfer of training is when an operator reverts back to responding to situations in the manner which he was previously trained.

Purpose and Use of This Report

The purpose of this report is to summarize existing literature or data which could be used to anticipate the negative effects of control room modifications on operator performance, especially under "high stress" conditions. Since the initial search for applied studies in this area failed to reveal concrete data, a review of theoretical issues was undertaken with special emphasis placed upon application of these principles to control room settings.

This report was prepared primarily for NRC personnel and human factors professionals who will evaluate and modify design decisions upgrading control room changes compliant with NUREG-0700.

The second section, "Control Room Changes and Transfer of Training," gives a brief description of the two major classes of changes—enhancements and retrofits—that will be made in control rooms. The topics of learning and transfer of training as they relate to operator performance in a control room are discussed. The basic principles underlying the transfer effect are summarized. Conditions under which transfer effects of various types can be expected to occur are identified.

The third section, "The Effect and Control of Change," discusses changes in society and the negative or positive effects these changes can have.

The fourth section, "Control and Display Illustrations," contains a series of illustrations that deal with control and display modification. Each incorporates an original design that represents a human engineering discrepancy (HED) and one or more options for redesign. These illustrations are intended to demonstrate in a practical way the concepts contained in the "Control Room Changes and Transfer of Training" section. They are not intended to cover all cases, and they should not be used as a formula for making retrofit design decisions. Their purpose is mainly to clarify concepts by means of concrete examples.

Neither the second or fourth sections require special knowledge or prior training in the psychology of learning. For a review of the basic and applied literature on transfer of training, consult Appendix A. This Appendix also presents suggestions for future research that were generated in the course of this brief study. The suggested research topics are intended to either confirm hypotheses for which there is only weak evidence or to answer new questions that have not yet been addressed but that seem particularly germane to control room operator performance following change.

CONTROL ROOM CHANGES AND TRANSFER OF TRAINING

Nature of the Anticipated Changes

A conscientious control room review will disclose from 200 to 300 human engineering discrepancies (HEDs).[2] Some HEDs will be major, others minor. HEDs may be scattered uniformly across all controls and displays or concentrated on a few panels.

For each HED the utility will, in most cases, be responsible for determining:

1. Its probable effect on human performance (i.e., its potential to induce error)
2. The consequence of incorrect performance on plant risk
3. Whether or not to reduce or eliminate the HED by some form of surface change or by major redesign.

Assuming that all HEDs have been identified, and that the three steps outlined above have been taken, the utility must next ask if the proposed correction or noncorrection of each HED will improve or impair operator performance. Will the change require some, a considerable amount, or no operator retraining? During the process of retraining, what are the prospects for negative transfer of training to occur? Or to state it differently, if a change is made and an operator has not been thoroughly retrained on the modification, what are the chances that he will revert to his previously trained manner of responding? These questions must be asked not only for individual HED modifications but for all HED modifications because the sum total of modifications represents either major or minor changes in the "stimulus and response environment," which will determine the effect of change on operator performance. The basic stimulus and response characteristics of the control board(s) shape human performance.

These behavioral characteristics are summarized in Table 1, where control room components are broken down into behavioral components. The general stimulus and response characteristics for displays, controls, and groupings of controls and displays are identified. From this analysis it is evident that each type of control room component has both stimulus and response characteristics. A component's stimulus and response value may vary as a function of whether it is responded to during normal or emergency operations. Awareness of this point is important because there is a tendency to equate displays with stimulus and controls with response. Since both have stimulus and response properties, these characteristics must be recognized if a proper understanding and application of human engineering and transfer of training principles are to be achieved.

These characteristics provide a convenient framework for describing the two major categories of change: enhancement and retrofit.

Enhancements. Enhancements refer to paint/label/tape additions and changes. They are made primarily to reduce identification and discrimination errors. Enhancements are used to correct inconsistencies between present labeling and/or color coding on different panels. On controls, added markings may help signify the correct direction of movement necessary for a specific operation. For both controls and displays, enhancements can improve the delineation of functional groupings.

Limitations to Enhancements: Population Stereotypes—Ingrained response tendencies result from long-term exposure to technology and its tendency to be standardized. These habit patterns are called population stereotypes or preferences. Such patterns may be characterized as expectancies for controls and displays to move in certain directions when controlling or representing such conditions as off and on; high and low; increase or decrease; or the value of a specific parameter on a scale, dial, meter, or other display. For example, we have learned to expect light switches to be on in the up position and off in the down; for the brake to be in a certain location in cars; for keys to lock and unlock in the clockwise and counterclockwise directions, respectively; and for screws to tighten when turned clockwise and to loosen when turned counterclockwise.

Design standardization facilitates ease of use but also promotes stereotypes. When the design

Table 1. Behavioral components of NPP control room panels

Control Room Components	Behavioral Component	
	Stimulus Characteristic	Response Characteristic
Display	– Position	– Localizing, reading
	– Shape, size, color, labeling	– Identification, discrimination
	– Informational change	– Evaluation of system status and problem/decision-making
Control	– Position	– Localizing, reaching, discrimination
	– Size	– Identification, discrimination
	– Scope	– Identification, type of movement
	– Markings/labeling	– Identification, direction of movement
	– "Feel"	– Fine adjustment
Related or grouped controls and displays (e.g. annunciators)	– Spatial relationships	– Proper control or display identification
		– Proper control response to displayed information
		– Proper sequential response to controls and/or displays
	– Consistency	– Consistent response to similar controls and/or displays

stereotype of an occupational group is contrary to that of the general culture, competition exists between the two stereotypes. In general, an individual will respond, based on the more dominant stereotype, where dominance is a function of the previous experience with the object working in an expected way or being in an expected place.

Since even the best enhancements usually will not overcome conditions that are contradicting to these response stereotypes, more extensive equipment modifications or retrofits of the type discussed next will be required.

Retrofits. Retrofits or backfits are more substantial design changes in which actual hardware modifications are necessary. They often involve positional changes or control/display modifications or substitutions which may be recommended for any one of a number of reasons. These changes frequently entail mechanical and back-panel electrical changes. Retrofits may be required in order to overcome any one of a series of HEDs. A control may be difficult to reach, for example, or a display may be too distant from the operator's visual field for easy identification and reading. Controls or displays may need to be reconfigured due to the fact that they are out of sequence or not functionally grouped. Related displays and controls may be repositioned because their functional relationships were not logically apparent. Changes in control or display design (shape, scale, control movement, etc.) may be made to make them more discriminable, comparable to other functionally similar components, or to conform with population stereotypes. Retrofits, because of the expense involved, are ordinarily employed only when an HED cannot be eliminated by enhancement techniques.

Potential Effects of Control Room Changes on Operator Performance—Transfer of Training from Pre- to Post-Change

Defining Transfer. Since transfer of training generally refers to the effects of past learning upon future learning and performance under a new set of conditions, a basic understanding of learning is necessary before transfer can be fully understood.

Learning can be defined as a progressive, incremental change in an individual's performance level as a function of reinforced practice. In human performance situations, reinforcement may consist of formally designated rewards (e.g., pay increases or promotion) or more informal rewards (e.g., successful task completion, praise, sense of accomplishment, etc.). Performance feedback from successful task completion is probably the most powerful reinforcer in most work situations. In skilled tasks, training usually occurs under highly structured conditions, and when asymptopic performance is reached, learning is considered complete.

When a task has been learned to a high level of proficiency, if the nature of that task is changed, it is important to understand the potential influence of the already learned habits upon performance under the new conditions (referred to as the transfer task).

Positive and *negative* transfer, respectively, refer to the facilitative or inhibitory effects of prior learning upon transfer performance. In nuclear power plant (NPP) control rooms, the conditions of performance are changed when (a) a trainee goes from a simulator to a control room; (b) a licensed operator goes from the control room back to a simulator for requalification training; (c) a major or minor change is made in the man-machine interface in the control room, including procedural changes; and (d) an operator is reassigned from one control room to another or changes jobs to another control room. All represent differences in the conditions under which learned performance occurs. Both HFE changes and the transfer effects from pre-design tasks contribute to improved operator performance.

The remainder of this section is devoted to the following questions:

1. What is known about transfer?

2. What are the implications of transfer for operator performance following control room redesign?

Illustrations that embody the principles and conclusions derived from this discussion are presented in the third section.

Transfer Findings and Principles. Most research on transfer has been conducted in laboratory settings. However, from this research come findings and generalizations which have been validated in more realistic applied settings. The bulk of the theoretical research (see Literature Review Section) has been conducted in the area of verbal learning. The principles derived from this work have been, to varying degrees, operationally tested. Simulation studies, especially with aircraft, are also of interest since they deal with transfer between a simulator and the actual aircraft, which differ in many significant ways.

Although many problems, situations, and variables have been studied in the different areas of transfer research, those basic findings and related principles which are generalized can be summarized concisely; these are summarized in Table 2 and discussed next.

Negative Transfer—There seems to be one fundamental way substantial negative transfer is produced. This occurs when new, conflicting responses on the transfer task are required while stimuli identical or similar to those used in the original task are retained. This is true primarily in transfer situations in which the response dimension (e.g., directional movement of a control or control position) remains the same for second task. In particular, reversing the responses to different stimuli produces the greatest negative transfer. Negative transfer of this type is also the most resistant to being relearned or retrained. As an illustration, Stewart (1981) discusses a change which a major automotive manufacturer made in the design of a new model: they reversed the relative position of the light switch and cigarette lighter from that of the old model. A number of drivers, who changed from the old to the new model, pushed what since had become the light switch while they were preparing to light a cigarette; in some cases the consequences was a fatal accident.

It should be pointed out that response changes which involve new dimensions or modalities do not necessarily produce negative transfer and sometimes produce just the opposite, positive transfer. For example, in experiments in which subjects are shifted from verbal responses to motor responses for the same stimuli, positive (rather than negative) transfer is frequently found.

Positive Transfer—A number of variables that contribute to positive transfer have been isolated. One, for example, is predifferentiation (or prelabeling) of stimuli; learning to discriminate stimuli in a training task produces substantial positive transfer to a post-change task. Another source of positive transfer is response learning. If the responses on two tasks are both similar and fairly difficult, having learned them on the original task may greatly facilitate learning of the second task.

Probably the most important variable in many transfer situations, depending upon the nature of the tasks, is the cognitive and conceptual relationships (psychological fidelity) between the training and the transfer tasks. In aircraft simulation studies, low (physical) fidelity simulators have generally produced a high degree of positive transfer to actual operation of the real aircraft because of the strong psychological fidelity of simulator tasks to actual flight demands placed upon the pilots.

The Effects of Stimulus and/or Response Similarity—As mentioned in Table 2 under "Mediating Principles," there is a continuum of similarity and difference between the stimuli and/or the responses on the pre-change and post-change task. This is illustrated in Figure 1, in which the outer "Post-Change" area represents the stimulus and response similarity in the pre- and post-change tasks. Starting from the upper-left quadrant ($S_1 - R_1$), in which the post-change stimuli and responses are identical to those in the pre-change task, changing the responses without changing the stimuli ($S_1 - R_2$) is likely to produce negative transfer. Thus, for example, retaining a switch while changing the settings on that switch is likely to produce negative transfer due to interference from the operator's established responses. On the other hand, changing *both* the switch and the required response will usually produce little transfer of any kind since both the stimuli and responses have been altered ($S_2 - R_2$). A stimulus change in the switch (e.g., size, shape, etc.) without any change in the response (e.g., locating, identifying, moving, etc.), represented by $S_2 - R_1$, usually will lead to positive transfer.

The Effects of Practice—A few comments should be made about the effects of practice upon transfer. As one might expect, increasing the amount of practice on a training task will increase the amount of positive transfer to be found in a

Table 2. Basic principles of the transfer effect

Primary Principles

1a. Negative transfer will be produced when responses which conflict with the original ones are introduced in the modified design.

1b. A possible exception to this principle is the case where pre-modification controls and displays either conflict with population stereotypes or are not designed consistently. In such cases, negative transfer may already exist and can be eliminated only through modification.

2. Positive Transfer usually will occur when responses are unchanged, even when substantial stimulus changes are made.

3. The greatest amounts of positive transfer are generally produced by maintaining the conceptual similarity of the original and modified tasks.

Mediating Principles (Technical Title in Parentheses)

4. There is a continuum of similarity/difference for stimuli and responses. The amount of positive or negative transfer varies depending where the new (post-change) stimulus or response falls on that continuum (see Figure 1). (Stimulus/response similarity gradient)

5. Any time operators understand how stimuli and responses relate to subsystem operation, i.e., the value or function of the information displayed or control moved, positive transfer will be enhanced. (Mediation)

6. Learning or practice under varied stimulus or task conditions will enhance positive transfer. (Stimulus generalization)

7. If the stimulus and response tasks are thoroughly learned prior to any control-display (C-D) changes, this will facilitate either relearning and/or positive transfer after C-D modification. (Original learning effects)

8. When verbal cues or names can be associated with the C-D changes and learned by operators, positive transfer will be enhanced. (Predifferentiation)

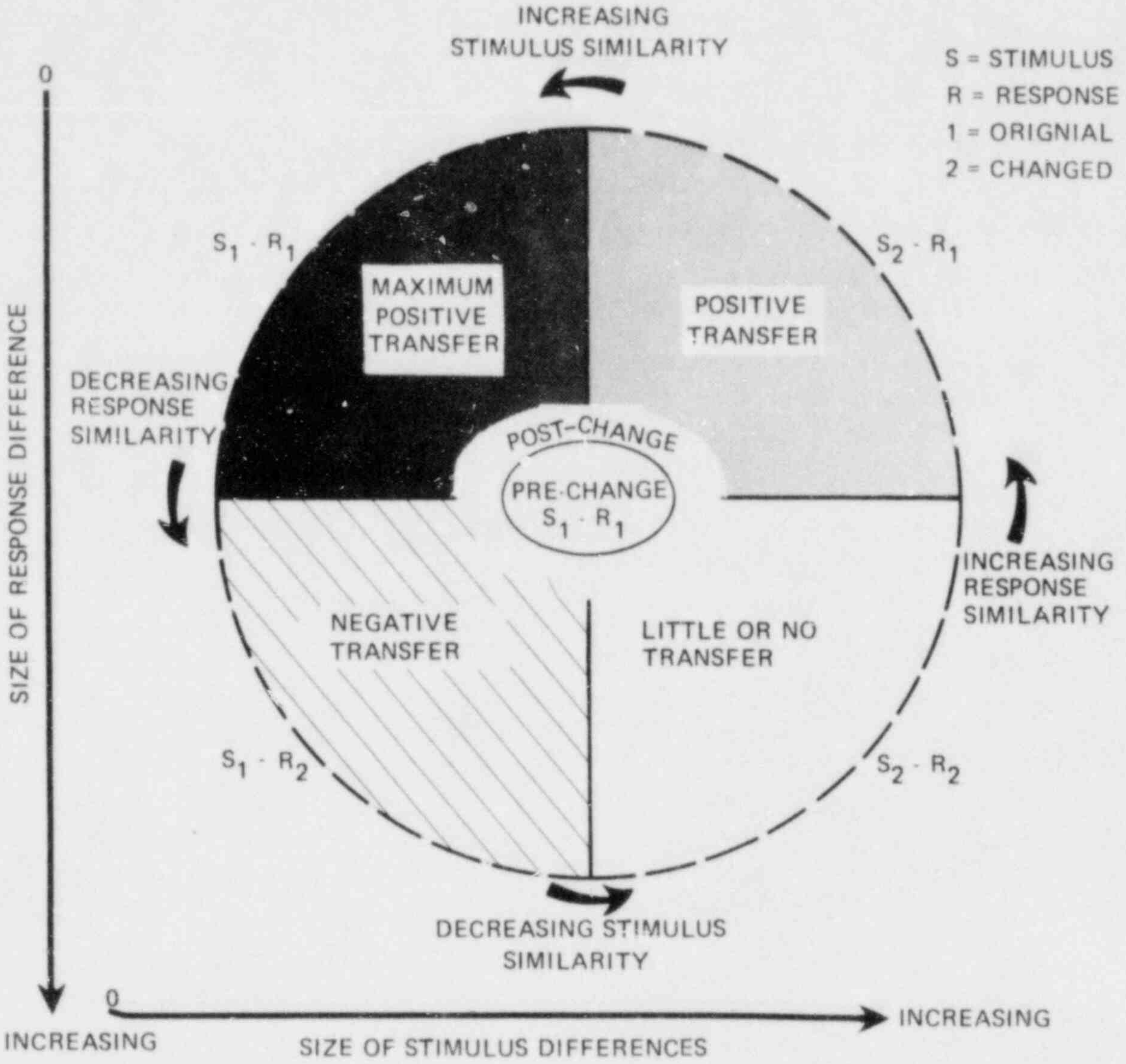


Figure 1. The role of stimulus and response differences upon transfer effects in post-change performance.

highly similar task. However, some evidence indicates that when negative transfer exists, high amounts of learning on the *first* task will reduce or eliminate negative transfer. Also given negative transfer to the *second* task, increased practice on that task will not only eliminate errors due to interference from the original task but will make even occasional transfer errors unlikely. One explanation for the facilitating effects from increased first- or second-task practice is that such practice produces task "differentiation" or a mental representation of each task as a whole, helping the subject or trainee discriminate one task from the other.

In general, whenever Principle 1a or 1b applies (see Table 2) more extensive retraining may be required. This should overcome both short- and long-term operator adaptation difficulties.

The Question of Stress—There are little data to support or refute the popularly held notion that increments in stress level produce regression to prior habits during task performance. In fact, the findings regarding the influence of stress upon even original learning are not conclusive. Thus, while it is possible that stress may predispose some individuals to return to earlier conflicting habits, at this point any conclusions would be pure speculation. More research is needed in order to establish the effect of stress on performance after a control room change.

The Matter of Applicability—A final consideration is that of how applicable the described principles are for a control room setting. Two problems exist. First, it is not always easy to determine what the stimuli and the responses are in control room operations. The principles of transfer-of-training and learning were generated in laboratories where very simple and describable stimulus/response conditions prevailed. In a control room, long procedures and sequences of events combined with hundreds of displays and controls can make precise stimulus and response specification difficult.[3] Therefore, without research to determine the generality of the transfer principles there is no assurance of their applicability or accuracy in a nuclear control room setting. Second, none of the primary mediating principles are quantifiable. Thus, for example, there is no common metric for readily measuring stimulus or response similarity and difference.

The implication of these two problems is that while the principles of transfer of training and learning provide a useful way of explaining what happened in various laboratory experiments, these principles do not fully and precisely account for effects that occur in the real world.[3] In any specific application, these principles suggest what to do or not to do avoid negative transfer, but the degree to which the various principles are used is a matter for expert judgement or empirical investigation. For example, existing principles cannot predict the amount of training needed to overcome old habit patterns (operator preservation) for various types of displays or control change. Nor can one place a particular control and/or display change accurately on the continuum represented in Figure 1.

In summary, more research must be done on transfer as a function of change before these principles can be applied with absolute confidence to control rooms. In the mean time, these principles provide general guidance, although they must be interpreted and applied with caution.

Acceptance of Change—Although operator acceptance of control and display modifications is not a traditional transfer-of-training question, it deserves comment since it theoretically could have a bearing upon post-change performance. Logically, one would not expect major resistance to change unless very basic aspects of a task were being changed. While substantial changes in technology are sometimes prone to operator rejection, there is no reason to expect this with simple control-display modifications. Also, a number of studies[2,4,5] have found that operators in both control room and non-control room settings tend to support control and display modifications that conform to human factors standards.

Overall Implications for NPPs. In general, control and display modifications made to eliminate HEDs, if introduced at once, will improve performance almost immediately after being introduced. Unless the conceptual and procedural nature of the operator tasks is radically changed, one can expect positive transfer from the original panel layout and design to the modified one. Much of what experienced operators have learned is of a cognitive (decision-making) nature that transfers effectively from the old to the modified control room. This is distinct from skill or rule-based behaviors which are more subject to negative transfer effects. Experienced operators also will have learned the discriminations and responses common to both the original and modified tasks and therefore will outperform relatively inexperienced and untrained operators, thus making fewer errors. For new operators—or operators transferring from other plants—redesign in itself should not pose a transfer problem; thus, personnel turnover should tend to reduce many potential transfer problems.

Of course it is possible that some changes will produce at least temporary decrements in performance. As Figure 2 indicates, design changes might be expected to temporarily detract from the performance of both experienced and inexperienced operators, assuming that the latter have had some training on the old design. However, retraining should quickly reverse such effects,

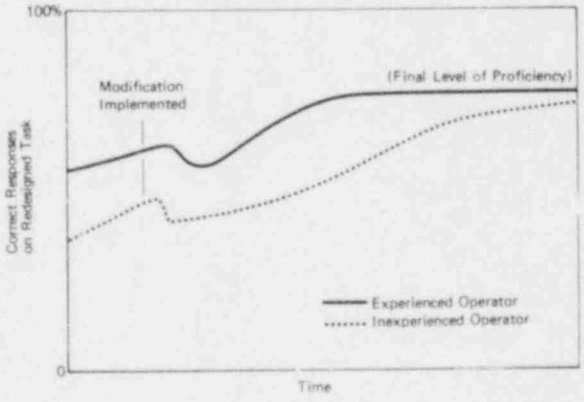


Figure 2. Theoretical performance curve for inexperienced and experienced operators following design modifications.

and experienced operators should reach peak efficiency rapidly, followed by inexperienced operators.

Based on the overall findings in the transfer-of-training area, the implications for NPP redesign can be summarized as follows:

- Generally, positive transfer to the redesign situation should be substantial.
- Proper redesign should eliminate much confusion resulting from inconsistencies among panels and violations of population stereotypes.
- Negative transfer can occur if the stimulus and response relationships between the original and redesigned controls and displays are not carefully considered. Following the principles given in Table 2 should minimize the potential for negative transfer.
- Given that control room modifications are carried out with the question of transfer in mind, problems of negative transfer should be reduced to a minimum, or quite possibly eliminated. What negative transfer exists should be eliminated with retraining.
- Plant turnover and the influx of new operators should further mitigate any problems associated with negative transfer.

THE EFFECT AND CONTROL OF CHANGE

Introduction

It has been said, "Nothing remains constant except change." This adage alone should make one sensitive to change and difference, if for no other reason than today man and machine are another day older. Change can often be thought of as stress on a system which was previously in a state of dynamic equilibrium. Change can also be viewed as anything which positively or negatively disturbs the planned or normal functioning of a man-machine system. History bears out the fact that a relationship between change and increased risk can exist. It has been demonstrated that for any functional system which has been operating satisfactorily (i.e., up to some standard), when problems do arise, deleterious changes and differences associated with *personnel*, *plant*, *hardware*, *procedures*, or *managerial controls* have often proven to be actual *causal factors* in the creation of these problems. Changes also have an indirect relationship with impending danger. For example, the jungle dweller has an acute awareness of his surroundings, a sense that remains dormant in most of us. This sensitivity warns him not only of direct danger, but of *changes* and *differences* in the patterns of jungle life, such as the eating habits of animals and the singing of birds, which could be preludes to impending danger. Not only in primitive societies, but in the modern industrial settings as well, change control and analysis should become essential elements in hazard identification and risk management.

The Change Analysis Process

Change analysis techniques were developed at the Rand Corporation, and improved by two former Rand employees, Charles H. Kepner and Benjamin B. Tregoe. Their book, "The Rational Manager" is a valuable resource in applying the techniques. Change analysis is a systematic approach to problem solving which can aid the manager in decision making, the appraiser in evaluating system functioning, and the accident investigator in identifying accident causes. The concept of change analysis allows the system analyst the latitude of determining whether (a) changes are needed in a stable operating system, or (b) if operational changes require safety-related counterchanges.

The first observation we can make is that our perception concerning the time span when change becomes necessary has decreased considerably. In ancient Egypt, things were done exactly the same way for entire dynasties, lasting millenia. In the Middle Ages, things were done the same way for centuries. In this century, change has taken place in terms of generations, i.e., 15 to 25 years. Now, however, our world is changing so fast that even things that are only two to five years old require change. What is the relationship between the effects of change over time. Figure 3 shows a rather pessimistic view of the exponential effects of changes over time as contrasted with the slow growth of safety-related counterchanges.

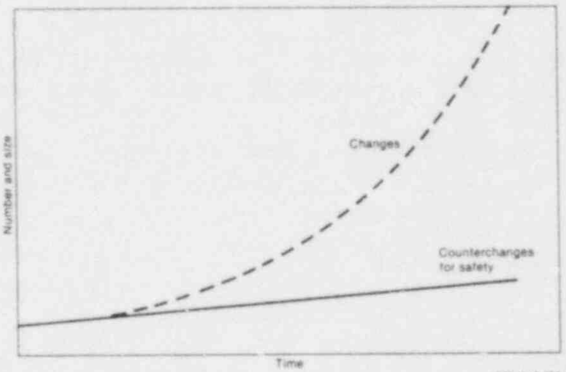


Figure 3. Effects of change versus time. The exponential effects of change over time are contrasted with the slow growth of safety counterchanges.

Many examples can be found of systems where the commonly used indicators and guidelines (accident/injury rates, the absence of bad accidents, etc.) indicate an acceptable program. However, the application of quite simple risk projection techniques could reveal a high probability for a severe accident. This could also be done by simply comparing the same overall system with itself as it existed earlier. The number of changes which have occurred without analyzing their consequences would probably amaze the evaluator.

The need for safety-related human engineered counterchanges is linked to the simple fact that any "real life" operational system is constantly experiencing changes in personnel, procedure systems, and equipment. Unfortunately, when such changes are made, often the effect on the entire system is not evaluated. These oversights or omissions may potentially lead to accidents or incidents.

Change-based analysis techniques are used in all walks of life from the nuclear control room designer to the medical doctor to aid in the following areas:

- *Trouble Shooting*—Knowing what additional facts are needed. Very often, the relevant facts are quickly available if their need is pinpointed. A change-based question format (i.e., what has changed?, or what is different?) is an efficient way to search for additional information.

- *Finding Obscure Cause*—At the initial stages of problem solving, who knows what the human causal factors might be? Therefore, it is important that *all* changes and differences are identified whether they appear to make any behavioral difference or not. Change and difference analysis quickly pierces the obscurity and helps prevent wasteful and ineffective action on false causes. The method helps to identify critical performance factors which are not obvious.

- *Analysis of Stress Behavior*—If change is not identified and controlled, it may soon compound and produce stress behavior. An example of stress behavior is where you have knowledgeable and competent personnel who nevertheless tend to make serious errors under abnormal or emergency conditions. If this is the case, the chances are quite high that they have been overwhelmed with change. Likewise, the initiation of uncontrolled or unmonitored change can compound or cascade to produce the same effect.

- *Quick Entry Into Problem Solving*—When time is short for problem analysis and the need for remedial action is urgent, change analysis techniques provide a systematic approach for quick entry into problem solving with very high credibility.

- *Avoiding Invalid Use of Old Solutions for New Problems*—Some managers have canned solutions for problems possessing certain characteristics. When a similar problem occurs, they apply the solution that worked the last time, only to find themselves treating symptoms of problems, rather than diagnosing and curing the cause. The application of change analysis can help avoid the improper use of old solutions for new problems.

Change analysis should be used by the analyst in two ways:

1. *Operational Change Control*—As a method of analyzing change in a system "before-the-fact." One must analyze known or suspected changes in a system, subsystem, or procedure to evaluate its effect on the process, along with recommending possible safety-related counter changes.

2. *Accident/Incident Change and Difference Analysis*—As a method of pinpointing changes and differences that may have had potential in causing an accident or near miss. A change analysis used in this manner would be an after-the-fact analysis and would be used to supplement suspected causal factor analysis and identification.

These two techniques are the topics of the next section and should indicate what effects the change had or will have on the immediate human and equipment components of the system. One should remember that all parts of a system are interrelated and a determination must be made as to its effects on other components and, subsequently, the entire system.

Operational Change Control

Change analysis is an effective tool in searching out potential problems associated with proposed design changes in a stable operating systems. A formal change review system is essential in the control of this change, which would review proposed changes in personnel, plant and hardware, or procedures and managerial controls. Also necessary in operational change control is the need for supervisory documentation change, and the need to monitor for its effect. The role of NRC in change analysis and the management of change cannot be overemphasized. An organization that is aware of change analysis techniques can correct problem areas which are sometimes inadvertently built into a new facility or equipment modification. Change is essential in our modern technology but the *management of these changes for safety* is paramount.

Change Review System. Systems that encounter extensive hardware changes may generate additional unintended behavior hazards. One needs to be sensitive to the nature of change and to changing situations—transfers, new machines, new materials, new operations, modifications, shutdowns, startups, etc. Sensitivity to change and the possible need for an offsetting counterchange is a mark of excellence for a manager, supervisor, or safety professional. One needs to explore training methods and data to sensitize supervisors to detect and react to significant negative changes. In systems theory, review and counterchange should follow every significant change. In complex systems, particular attention must be given to the compounding of change. For example, in one case investigated, a change made five years previously and a change made shortly before an accident combined to produce undesired consequences. Another factor which must be considered is the introduction of gradual change (e.g., deterioration of equipment or growing laxity in administrative controls) as compared with the discontinuous change (e.g., a modified hardware configuration or presence of a new employee).

Traditionally change-based analytic techniques are not being used for preventive, before-the-fact work to decrease both operating and safety problems. The needs seem to be:

- Establish the significance of any control room changes in causing trouble, beginning with top management statements and action. Then sensitize and train middle management. Then do the same for supervisors.

- Establish a routine analytic format for efficient, effective analysis of changes—a reviewable, visible method.

The potential problem worksheet in Figure 4 can be initiated at the inception of new modifications and expanded as the project develops. As the differences from the past are exposed, appropriate human factors expertise can be brought to bear. Experience indicates this low-cost form of analysis is amazingly effective in drawing appropriate attention to the causes of future problems and will give visibility to changes and differences which would otherwise be overlooked.

If a particular control room change is a cause of potential trouble, why wait for the problem to surface before doing the necessary analysis?

Monitoring for Change. It seems apparent that most complex systems depart from original plans and procedures to some degree over time. Therefore, the need exists to detect deviations (changes), initiate corrections (counterchanges), and in general ensure that goals are attained. Below are listed some of the elements necessary in monitoring for change:

1. *Planned Change Versus Unplanned Change*

   a. Planned change may require a scaled hazard analysis process (HAP) review, and affirmative safety action for certain specific control board modifications.

   b. Unplanned change (Behavior of Operators) must first be detected by monitoring. When detected, immediate preventive action should be taken when necessary, and a scaled HAP review should be triggered. Also, strong human engineering review requirements can help detect unplanned and unreviewed changes.

2. *Actual Change Versus Potential or Possible Change*

   a. Actual change is identified by reports and drawings.

   b. Potential or possible change requires behavior analysis and may be coupled with observations.

3. *Time Changes*

   A management monitoring system should be able to identify the deterioration of a process over time, and the interaction with previous changes.

Change-Based Potential Problem Analysis Worksheet

Specify Problem ____

Factors	Present	Prior Comparable	Differences, Distinctions	Affecting Changes	Counter Changes

INEL-A-16 364

Figure 4. Change-based potential problem analysis worksheet. The change-based potential problem analysis worksheet shows a preventive counterchange column. The changes in a project as compared with recent conditions or comparable projects can be specified.

4. *Organizational Changes*

   Shifts in unit responsibilities may leave interface gaps, particularly when the hazard analysis process is ill-defined. The monitoring system should help detect these types of problems.

5. *Operational Change*

   Monitoring should help detect changes in procedures and processes which require safety review.

The change-based accident analysis worksheet (Figure 5) provides examination of 25 potential factors, but even that number is not fully definitive, and the analyst should not hesitate to add to the list as the actual event dictates. Figure 5 provides a basic format for change analysis. This format is intended to provide general guidance and suggestions in exploring potential affective changes which might be contributory to this accident. Figure 5, as presented, will seldom be used to tabulate the analyst's findings. Large easel or desk pad pages, ruled in column format, can be used as worksheets.

Initially, the findings and comparisons do not come out in logical or subject order from various witnesses and documents. Rough notes can then be reorganized on a sheet with rows similar to Figure 5, but modified to fit the event. Headings which reflect a time or process often improve the analysis.

In Figure 5, the first three columns, the present situation, prior comparable, and differences (regardless of potential effect), should usually be completed prior to completing the fourth column which represents judgments as to whether the changes affected the accident itself. Be flexible. In the columnar spaces the characteristics of the accident/incident situation should be specified as precisely as possible:

1. Consider present control board configuration and operation.

2. Consider planned modified situation (or most nearly comparable situation).

3. Compare the two to detect potential changes of differences in operator behavior under high stress situations.

4. List *all* the differences without evaluation or value judgment or significance (seemingly insignificant differences can work together to cause serious problems or accidents) and obscure causes can emerge! So list *all* differences.

5. Analyze the differences for effect on causing the undesirable behavior, looking for both independent and collective contributions and not overlooking any of the man-machine interfaces.

6. Integrate the information relative to causal factors into the design decision appraisal process.

This is a simple six-step process to analyze and integrate the results into your system improvement efforts. This process is indicated schematically in Figure 6.

Also, one needs to consider the use of different reference bases for analyzing different aspects of the same change. For example:

- Compare the new hardware operation with a comparable hardware and operating situation before the modification

- Compare with a high stress situation; for example, one in which emergency action-amelioration was handled well for purposes of evaluating deficiencies in the emergency action-amelioration phase of the accident.

In seeking relevant distinctions, it is productive to compare the present problem in terms of the same object the day before, the week before, the month before, the year before. At first, the question "How is this different from the week before?" seems a little silly. But, when the distinctions and changes emerge, they often prove to be important.

When causes are not easily perceived, the visibility given by the matrix to known information allows human factors analysts to exercise their knowledge or expertise in identifying causal factors. If possible, however, experimental verification of cause is recommended.

Change-Based Accident Analysis Worksheet

Subject ______________________________

	Present Situation?	Prior, Comparable?	Differences?	Affective Changes?
What Object(s) Energy Defects Protective Devices				
Where On the Object In the Process Place				
When In Time In the Process				
Who Operator Fellow Worker Supervisor Others				
Task Goal Procedure Quality				
Working Conditions Environmental Overtime Schedule Delays				
Trigger Event				
Managerial Controls Control Chain Hazard Analysis Monitoring Risk Review				

INEL-A-16 363

Figure 5. Change-based accident analysis worksheet. The factors are only suggestive, and the worksheet is not a form to be completed. Analysis is done with a blank sheet, ruled as in the figure, and tabs modified to fit the event.

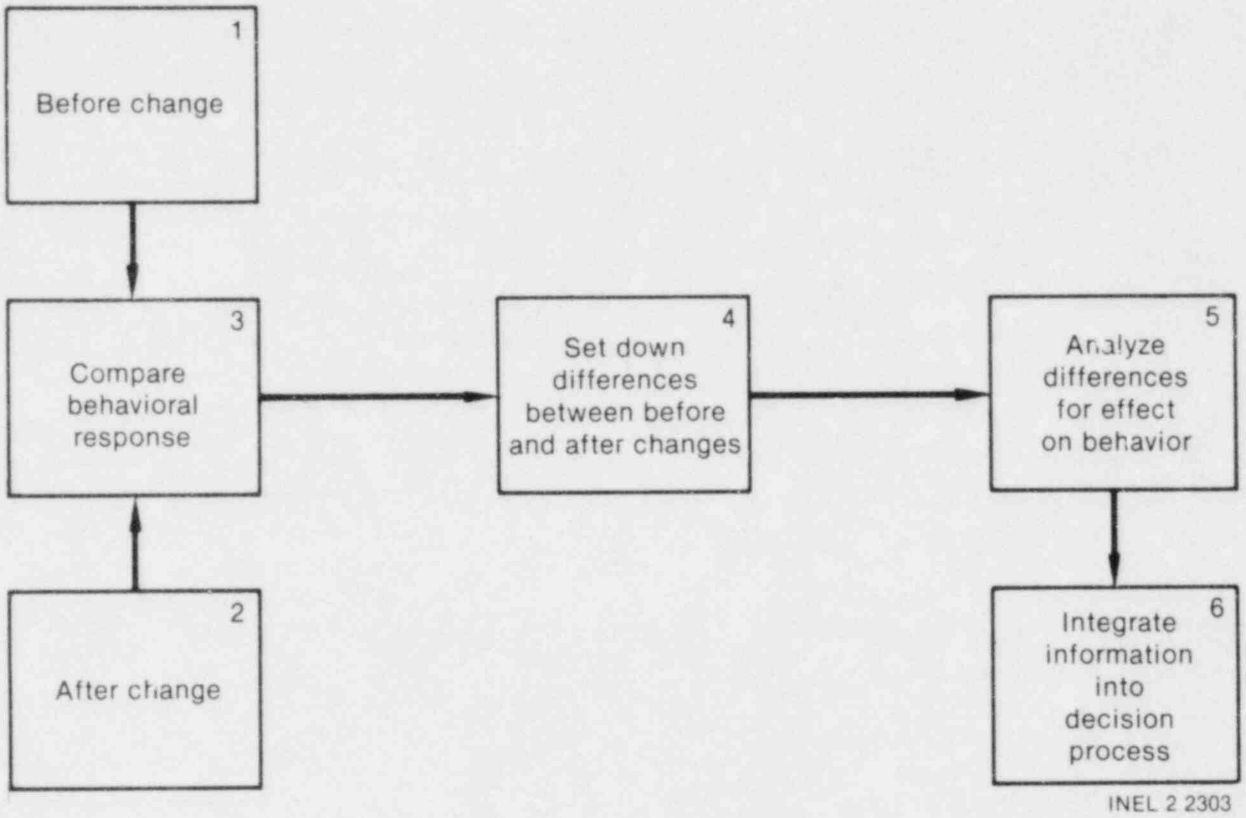


Figure 6. Change analysis schematic—the six steps in change analysis.

CONTROL AND DISPLAY ILLUSTRATIONS

Illustrations dealing with control and display modifications are presented on the following pages. Table 3 lists avoidable types of negative transfer errors most likely to occur as a result of design changes. The following illustrations (Figures 7 through 20) help to clarify the conditions under which negative transfer is likely to occur and suggest some ways to avoid it. These are not to be interpreted as rules for redesign, and should not be considered absolute.

Each illustration incorporates an original design and one or more options for redesign. Although the situations are intended to be realistic, some of the "bad" options may seem unlikely. However, most are based upon actual situations.

Table 3. Avoidable types of negative transfer errors most likely to occur as a consequence of design changes

Type of Error	Reason for Negative Transfer
1. Control or Display Misidentification	– Reversal of relative position of a control and display – Change in label position without appropriate demarcation – Repositioning near similar controls or displays without proper precautions – Moving instrument in location previously occupied by another – Correcting mirror image (full or partial) without sufficient demarcation
2. Improper sequence in reading displays or activating controls	– Reversal or partial reversal of original sequence – Change in arrangement without indication of horizontal or vertical sequence
3. Misreading a display or control	– Change in scale directionality
4. Incorrect control movement	– Reversing control direction without sufficient labeling or color coding

PROBLEM:

Some utility operators have expressed concern over the use of CRT graphic displays and controls over conventional hard-wired control boards.

EXPLANATION:

Human response to one stimulus (conventional control boards) tends to generalize to other similar stimuli. If one wishes to minimize the danger of negative transfer then a completely different stimulus (new medium of display) would serve this objective. For example, if one is concerned that extensive control room modifications could result in operator response behavior which is inappropriate to the new design, then CRT graphic displays represent a totally new and different stimulus medium which would substantially reduce competitive response.

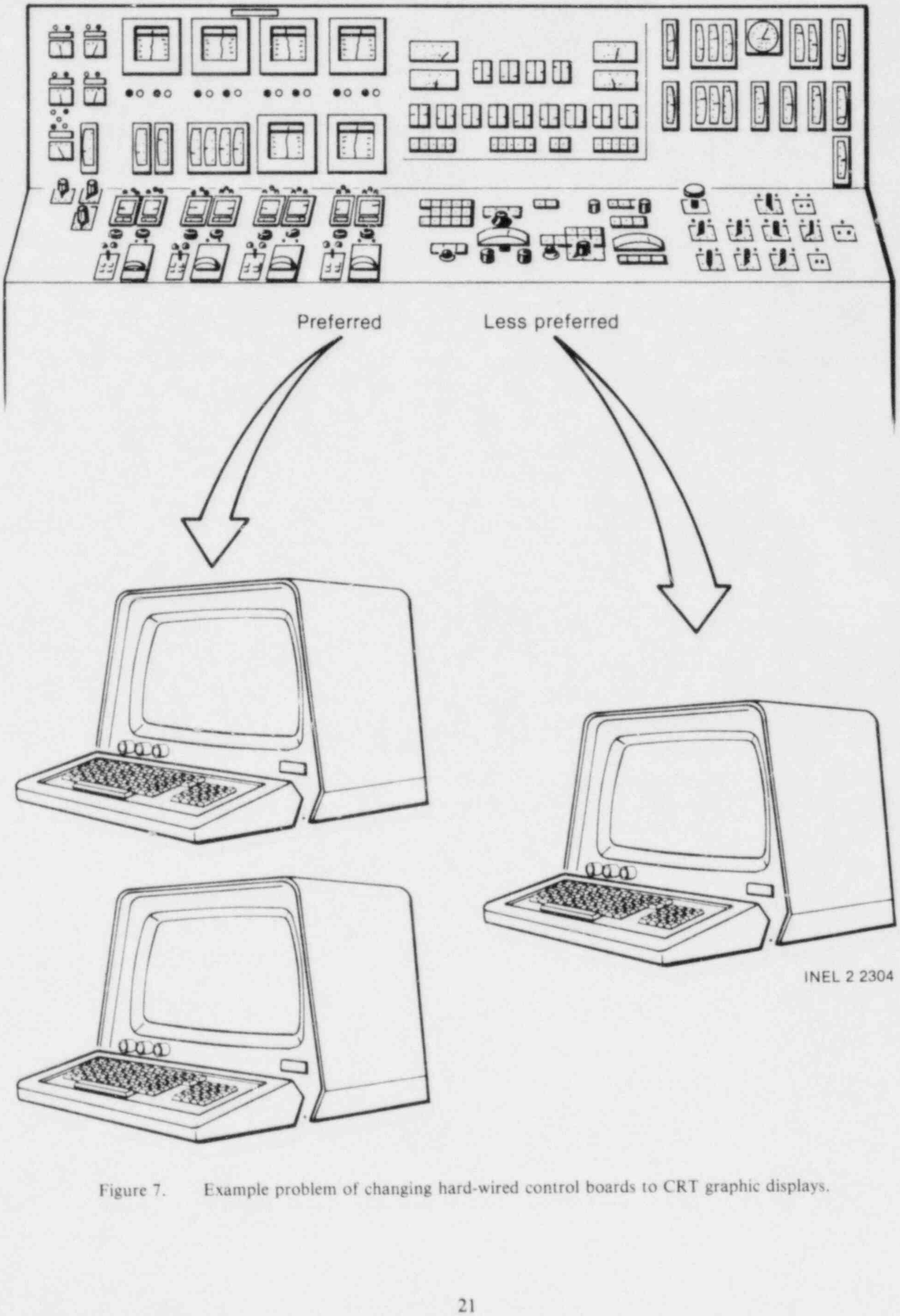


Figure 7. Example problem of changing hard-wired control boards to CRT graphic displays.

PROBLEM: The labels are underneath the controls and can be obscured by the operator's hand. Thus, the labels will be moved.

EXPLANATION: The danger of negative transfer in this situation lies in the fact that operators are accustomed to associating a label with the control positioned above it. The top alternative eliminates that possibility with the use of demarcation lines, while the bottom one does not.

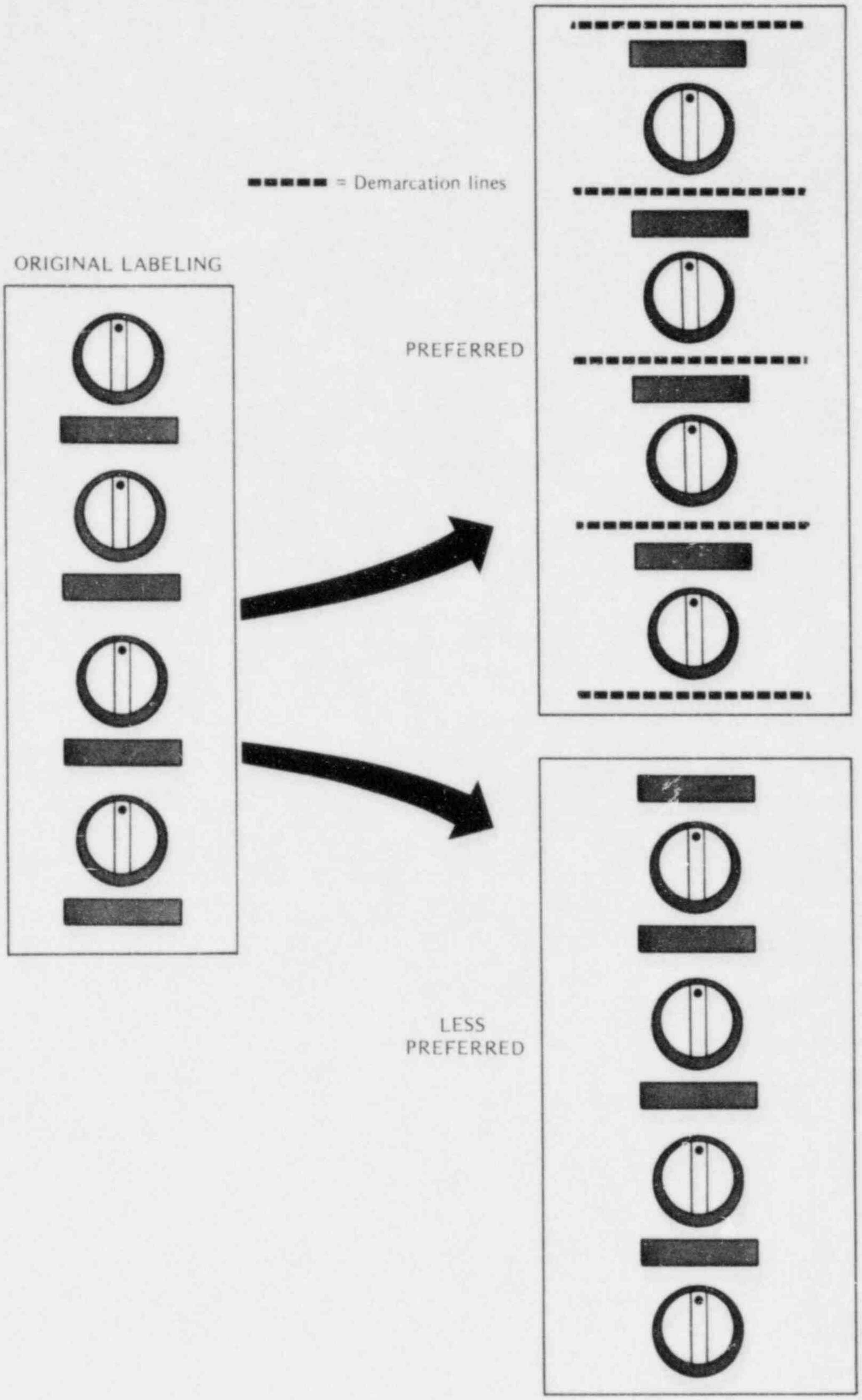


Figure 8. Example problem using demarcation lines to avoid negative transfer.

PROBLEM: The decision has been made to change the "on" toggle switches since they are reversed from those on the other panels and also since they contradict population stereotypes.

EXPLANATION: Given that the "on"—"off" positions are being reversed, appropriate coding and conformity to population stereotypes will make the reversed positions as clear as possible to the operators.

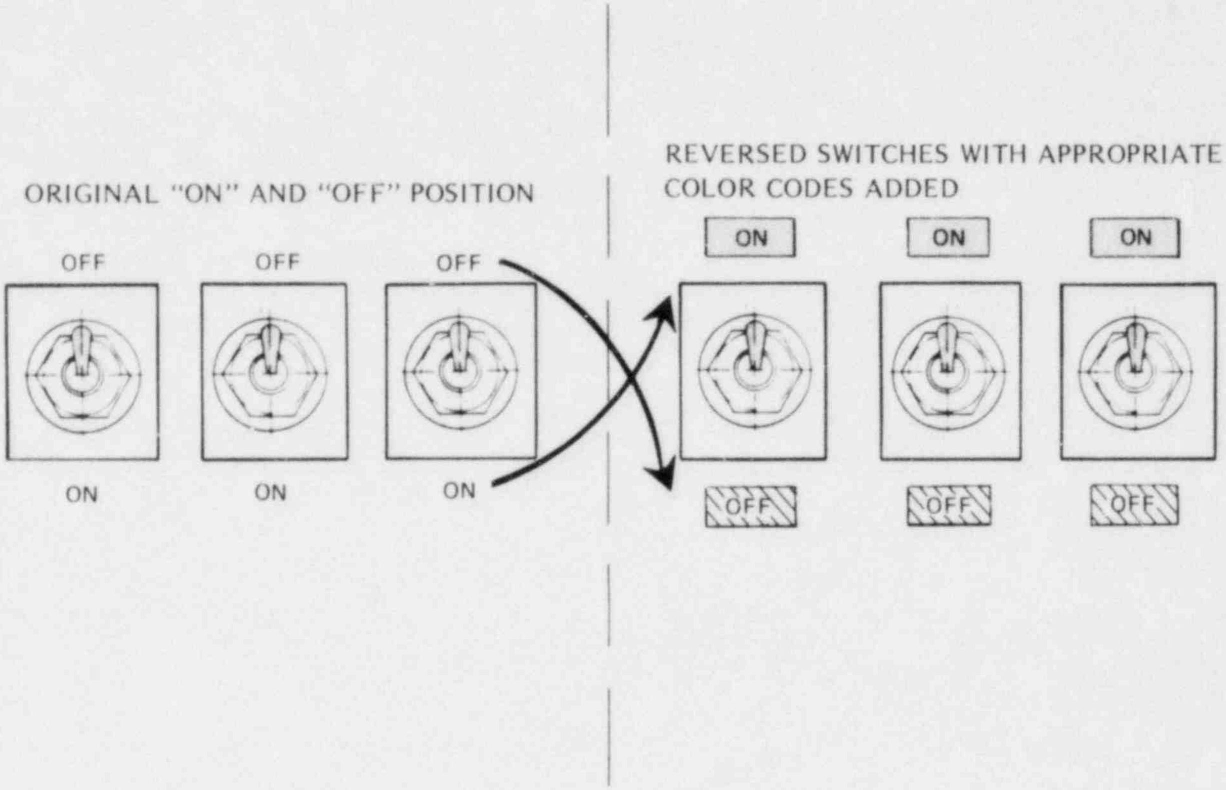


Figure 9. Example problem showing the need to conform to population stereotypes.

PROBLEM: Display color codes for the different system labels are difficult to discriminate and should be changed.

EXPLANATION: While the labels in both the top and bottom alternatives are easy to discriminate, the bottom example represents a simple oversight which could create transfer problems. If an operator retained an association between "blue-green" and display 3, he would be predisposed to misidentify display 1 readings.

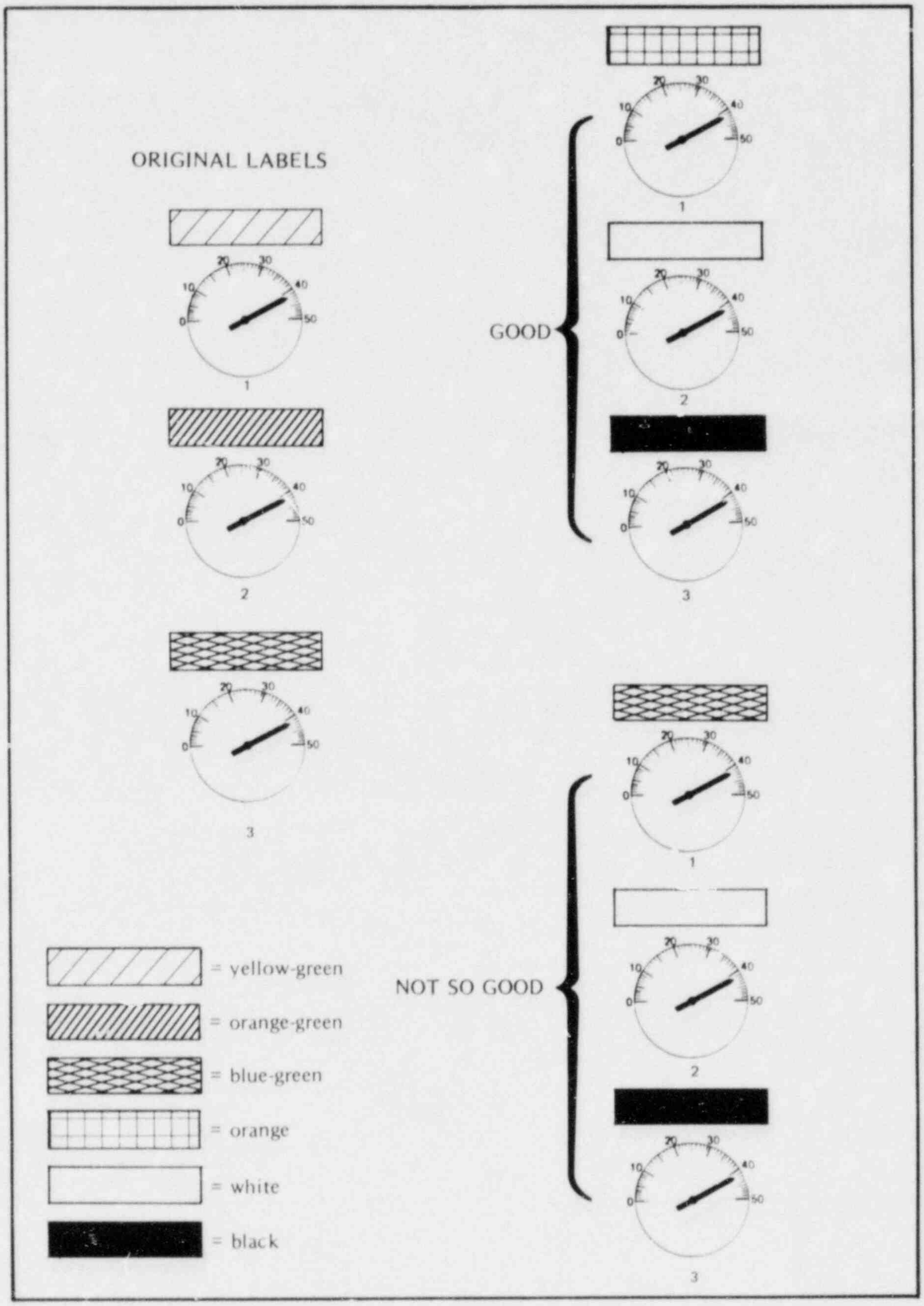


Figure 10. Example problem showing label discrimination problems and a transfer problem that could arise if label colors are not selected properly.

PROBLEM: The top legend-controls are difficult to reach and thus should be lowered.

EXPLANATION: The top alternative is preferable because it retains the basic perceptual relationship among the controls while at the same time moving the top controls within easy reach. Although the bottom alternative is not necessarily a bad one, because of prior experience (conditioning) operators may have some problem identifying the array rapidly.

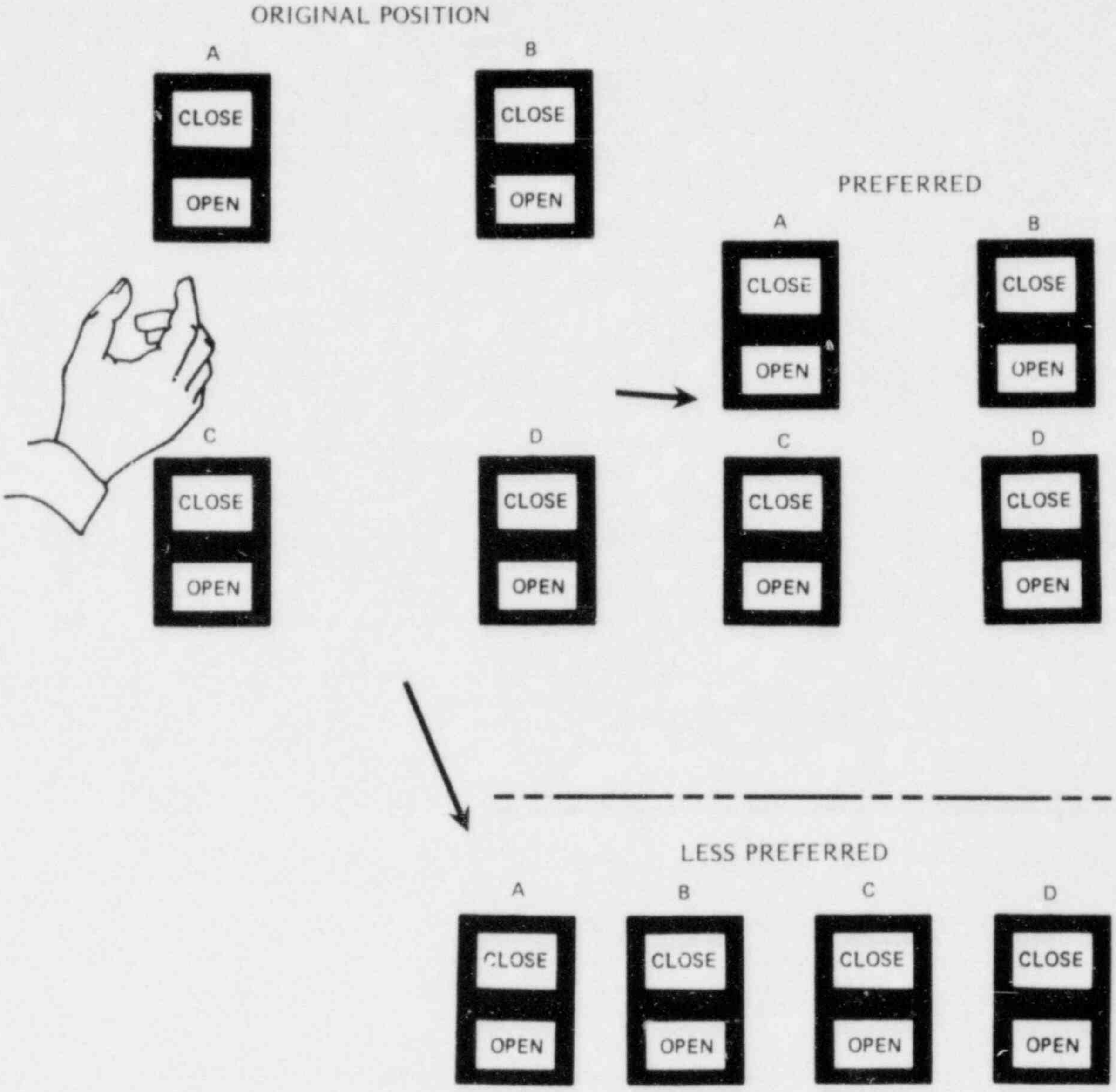


Figure 11. Example problem showing possible control board modifications when a control is difficult to reach.

PROBLEM: A partial mirror image is being corrected by control-display rearrangement and demarcation.

EXPLANATION: A partial mirror image presents the same kind of problem as a full mirror image—there is some possibility of negative transfer within the control room and in some cases within a given panel. However, eliminating the problem means reversing some of the control-display relationships, and this may produce some negative transfer from the old to the new array. This problem can be virtually eliminated by grouping the controls with their associated displays by means of demarcation lines.

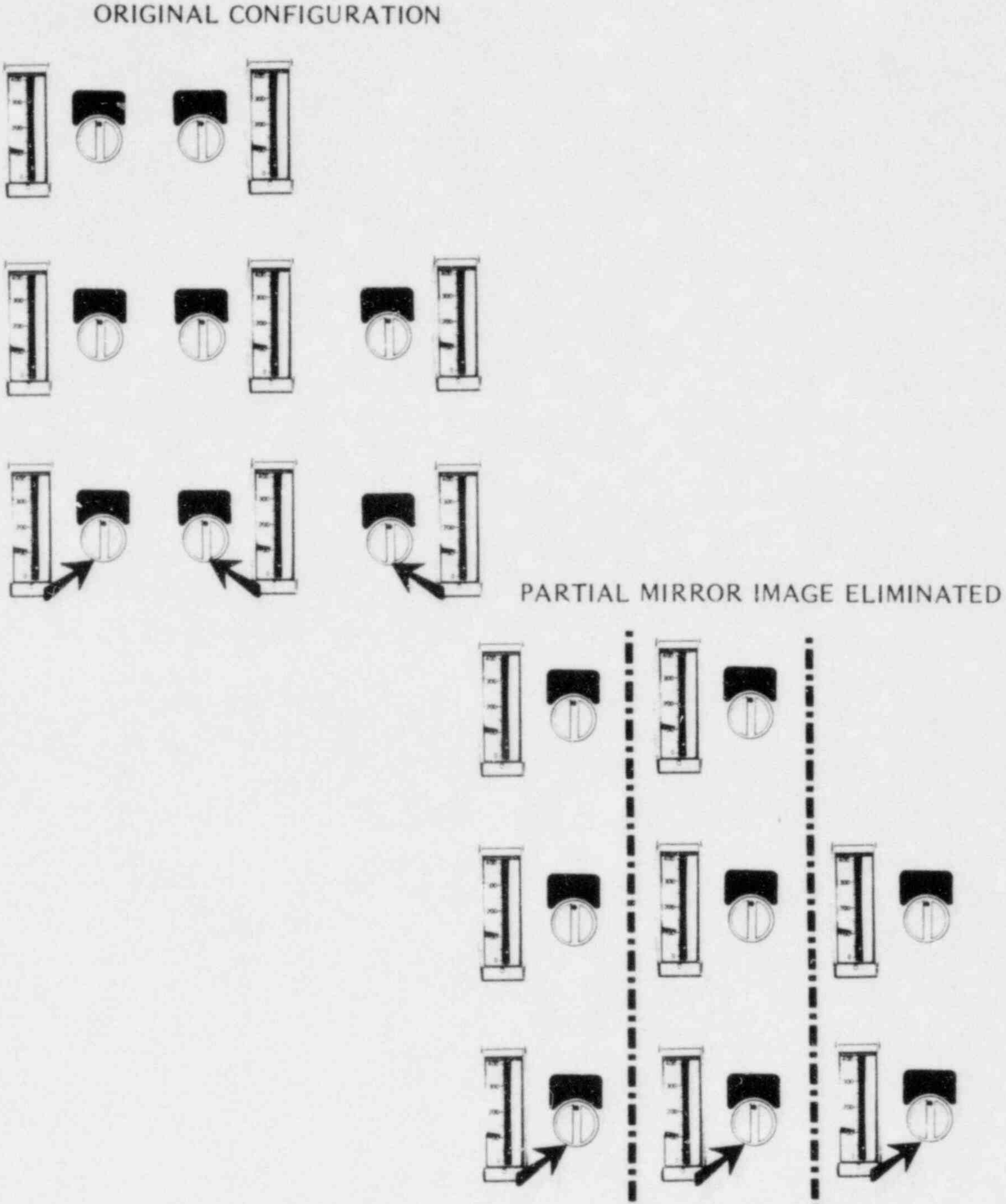


Figure 12. Example problem showing a partial mirror image being corrected by rearrangement and demarcation.

PROBLEM: The label needs to be changed to avoid misunderstanding/misreading.

EXPLANATION: Among the three alternatives—A, B, and C, Alternative A is the preferred one since there is virtually no change other than spelling out "feedwater." Alternative B is acceptable, but C could cause problems. Not only does C contradict HFE standards, but it may produce negative transfer since operators are accustomed to identifying the label with the display below it, not above it.

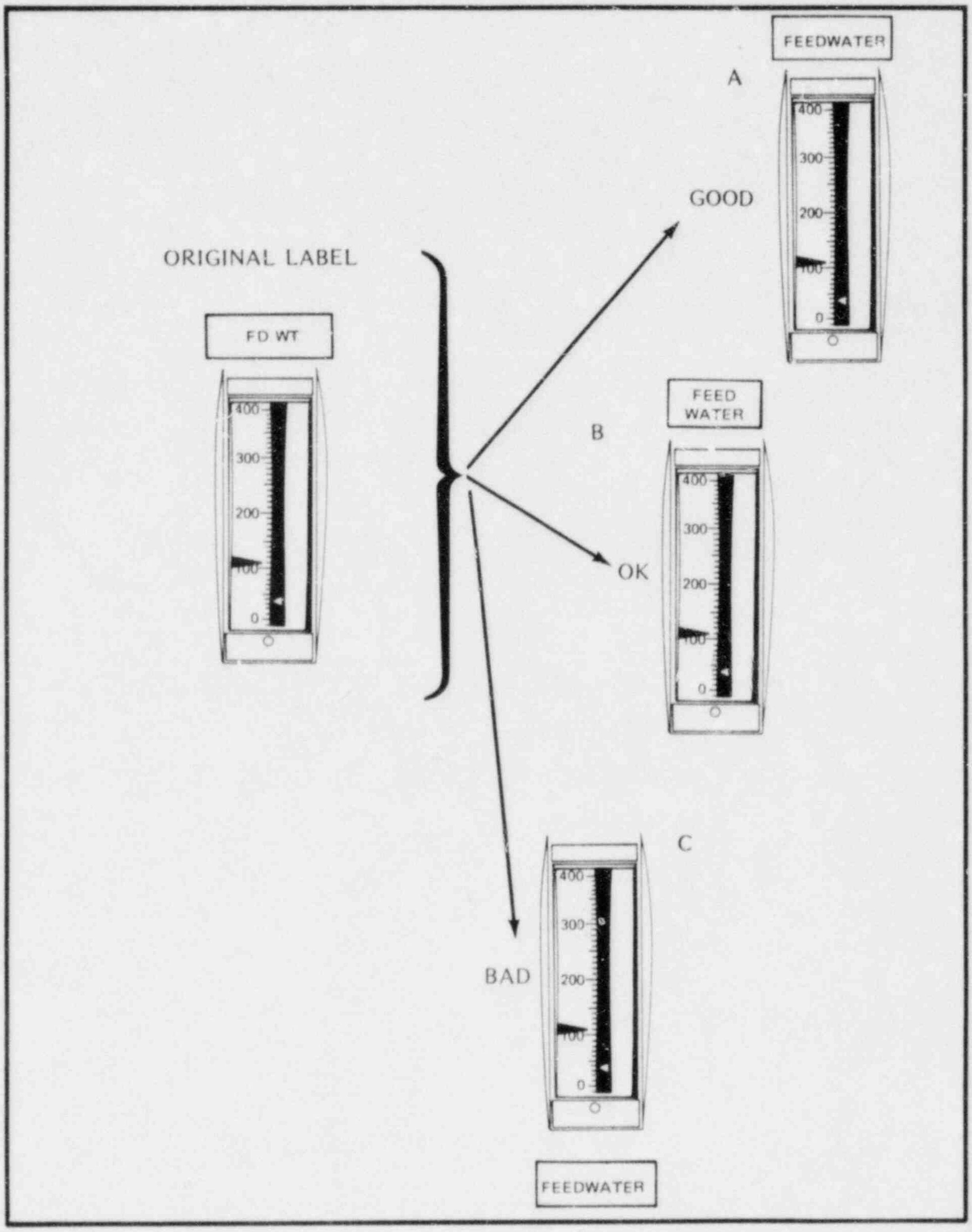
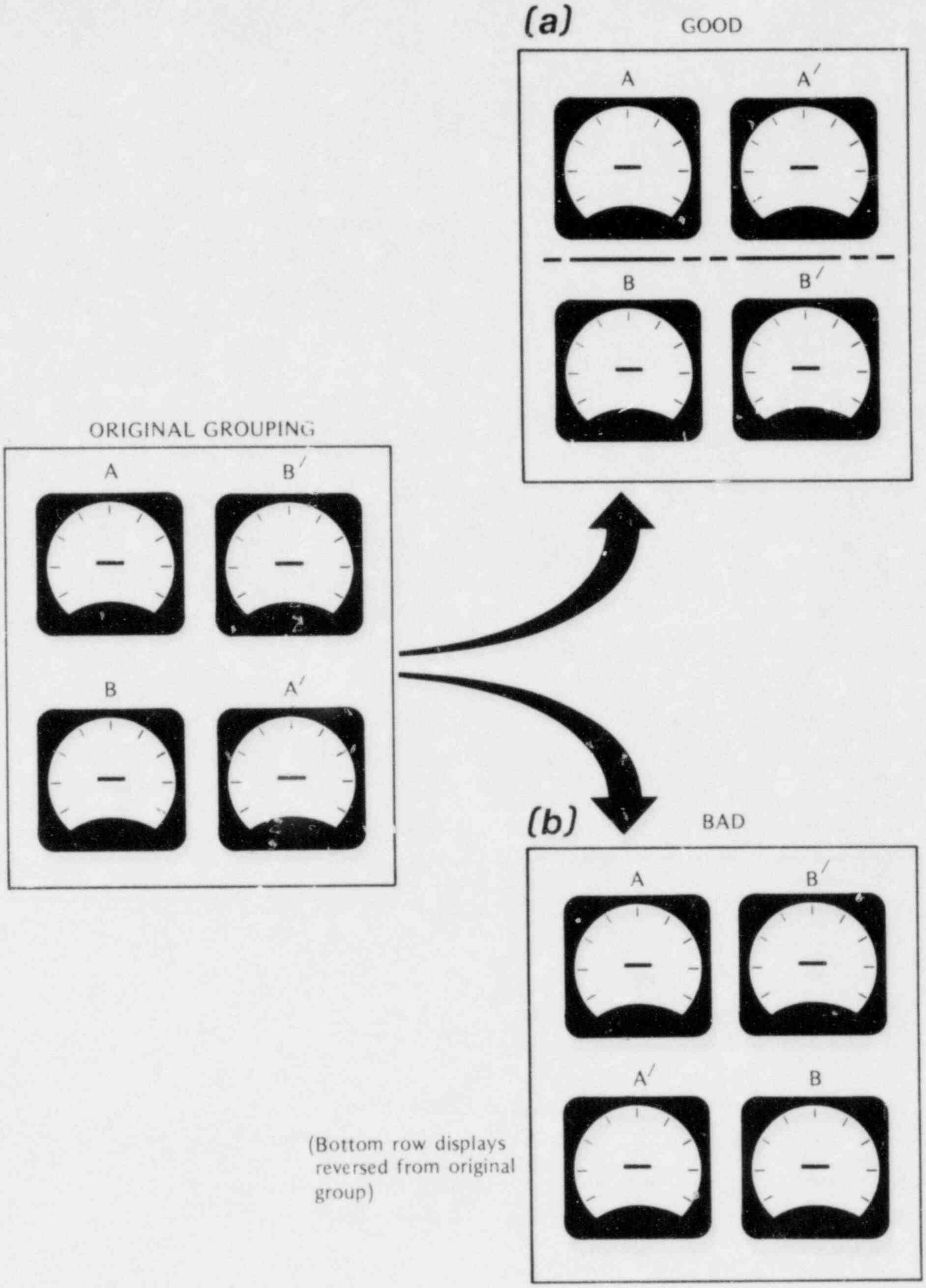


Figure 13. Example problem showing how to correct an easily misunderstood/misread label.

PROBLEM: The displays are not functionally grouped, and thus need to be rearranged.

EXPLANATION: Alternative (a) is good because it preserves the sequential relationship horizontally between the functionally related displays (A, A′; B, B′), and it will facilitate direct comparisons or sequential readings. Also, demarcation lines should eliminate any negative transfer resulting from diagonal comparisons made by operators with the original grouping.

Alternative (b) represents a reasonably likely modification having potentially serious consequences. Should B and A′ (original) be reversed (Alternative b), the vertical display sequences would become A, A′, and B′, B. The reversal of one sequence but not the other would constitute a more difficult problem than if both were reversed. In the latter case operators could at least learn a consistent rule (reverse order) in dealing with the new array.



(Bottom row displays reversed from original group)

Figure 14. Example problem showing how to rearrange displays so they are functionally grouped.

PROBLEM: The controls are close together and consequently are likely to cause discrimination errors or accidental activation.

EXPLANATION: Assuming that smaller J-handles are appropriate for the required operation, the top alternative reduces the possibility of discrimination errors or accidental activation. The bottom alternative may lead to errors in sequential operations since some operators may be inclined to respond top-down unless the array clearly indicates otherwise.

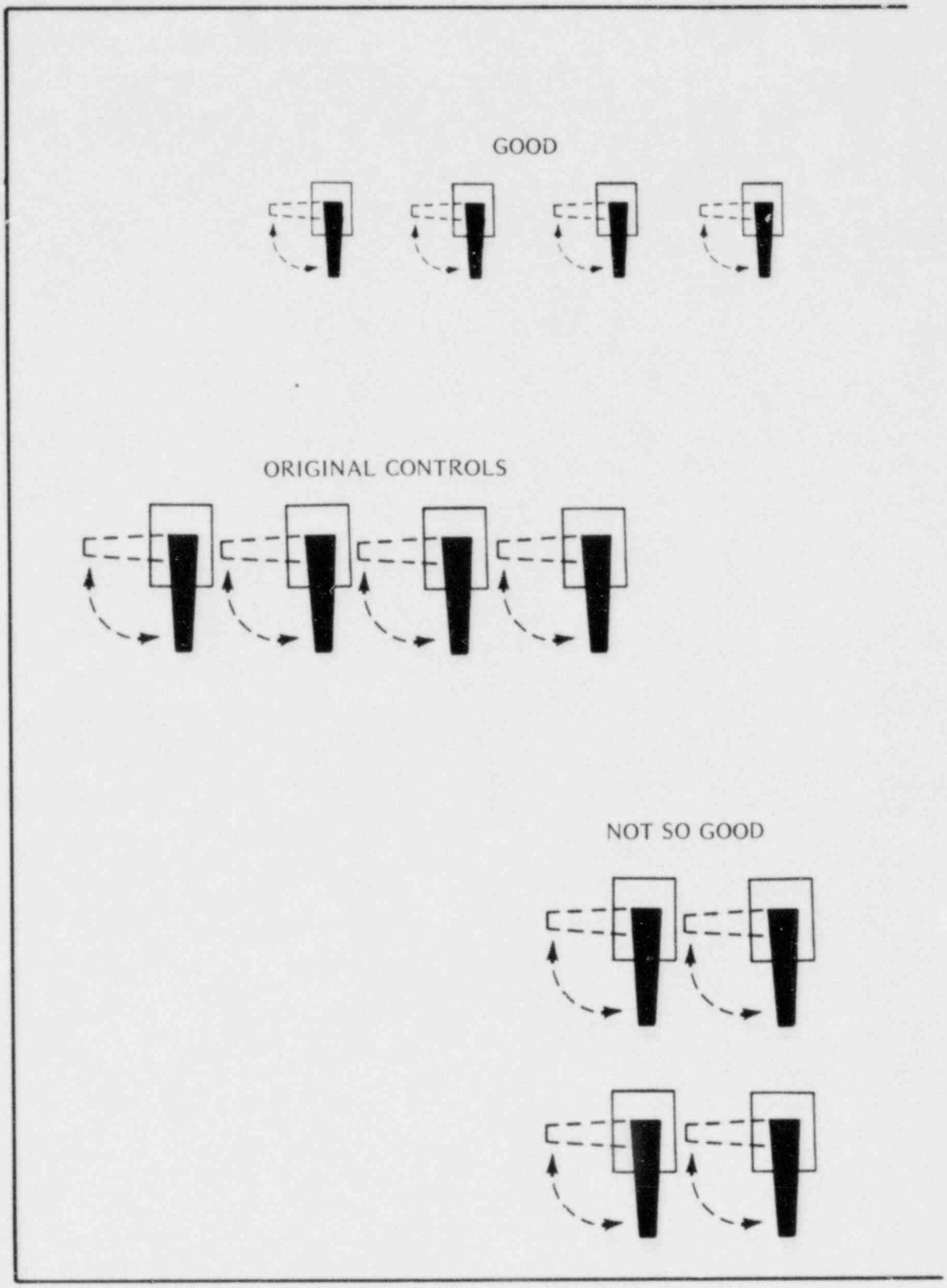


Figure 15. Example problem showing the best solution when controls are grouped too close together.

PROBLEM: The pushbuttons are too close together, both vertically and horizontally.

EXPLANATION: The top alternative preserves the configuration and sequence of the pushbuttons, while the one on the right retains the basic sequence but not the configuration. However, the bottom alternative represents relocation of the right-hand buttons (A and B/4, 5, and 6) and a resulting breakup in the control sequence.

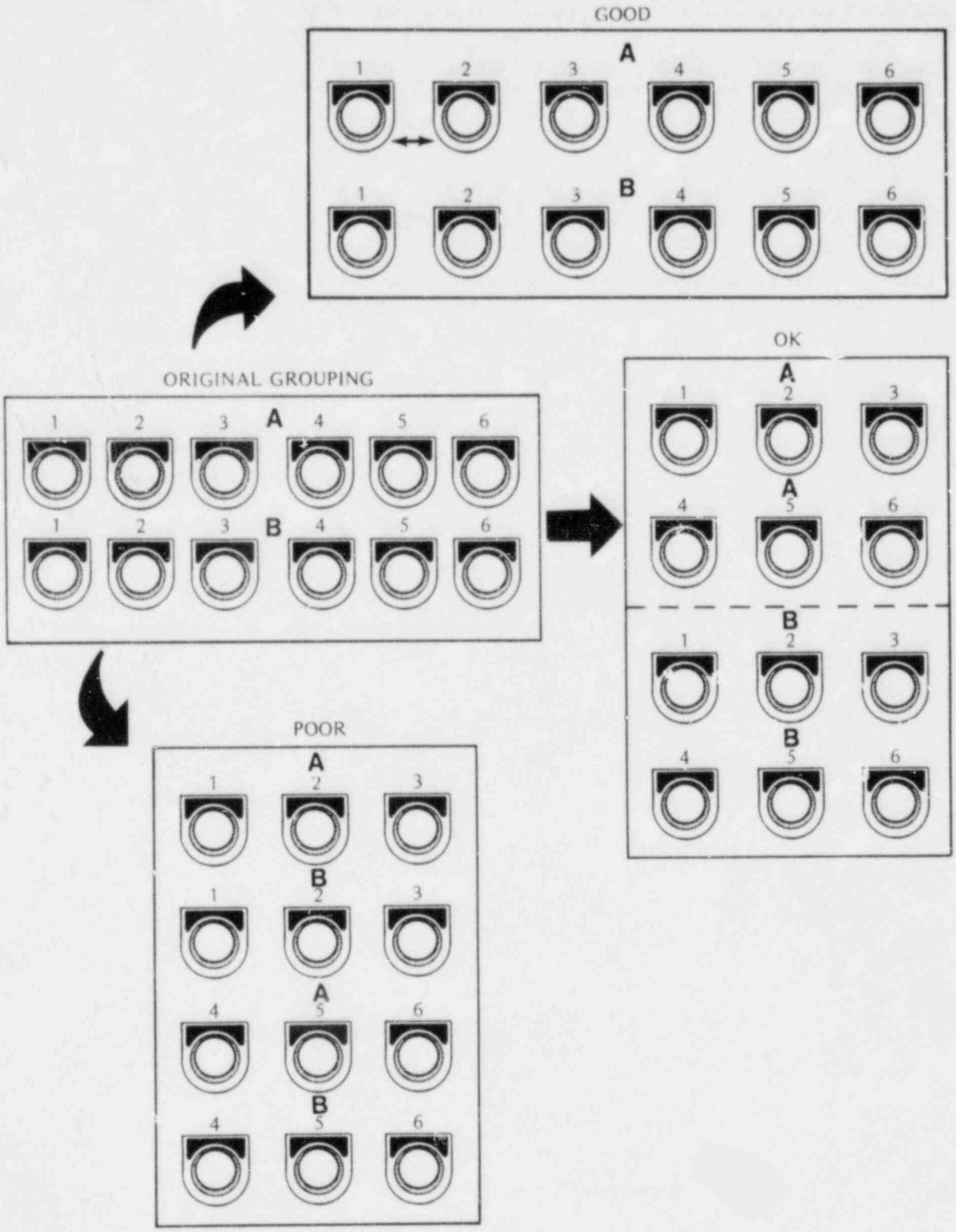


Figure 16. Example problem showing different possible configurations when pushbuttons are grouped too close together vertically and horizontally.

PROBLEM: Counter 1 is too high and should be repositioned for easier reading.

EXPLANATION: Alternative A (top) brings Counter 1 down into the operator's effective viewing area and maintains the relative positions of the displays, preserving both the visual and response characteristics of the array. However, the placement of Counter 1 in B (bottom) is likely to result in reading errors since operators are accustomed to reading the bottom display as Counter 5, not as 1.

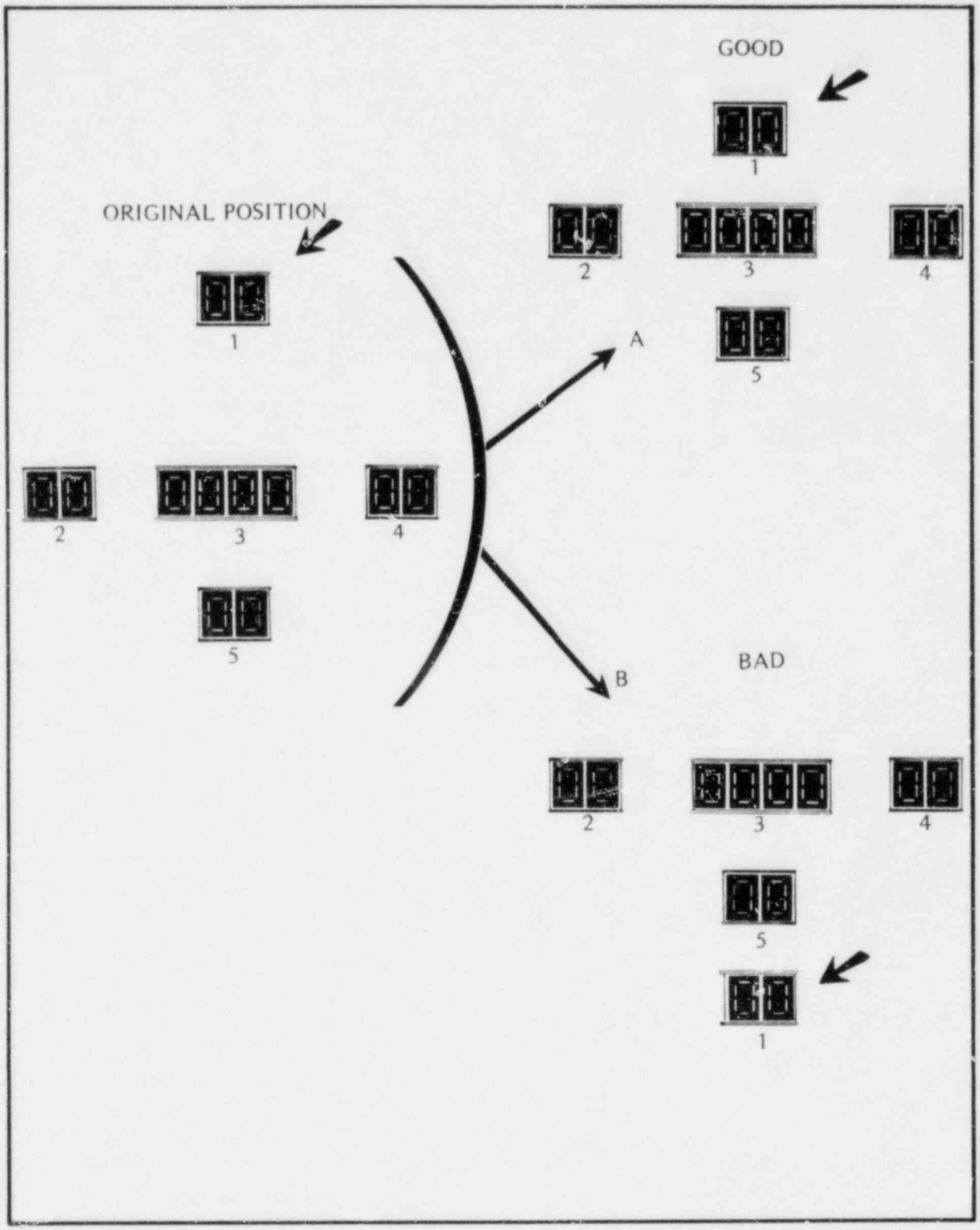


Figure 17. Example problem showing how an instrument (counter) can be repositioned for easier reading.

PROBLEM: The functional display groupings (1, 2, and 3) are too close together and are likely to be confused.

EXPLANATION: Ideally, the horizontal alignment of the displays will be retained (as in Alternative A); however, B may be acceptable if space limitations make that more practical. Alternative C represents a likely transfer problem in that operators accustomed to responding from left to right on the same row might respond to Display 3 as 2.

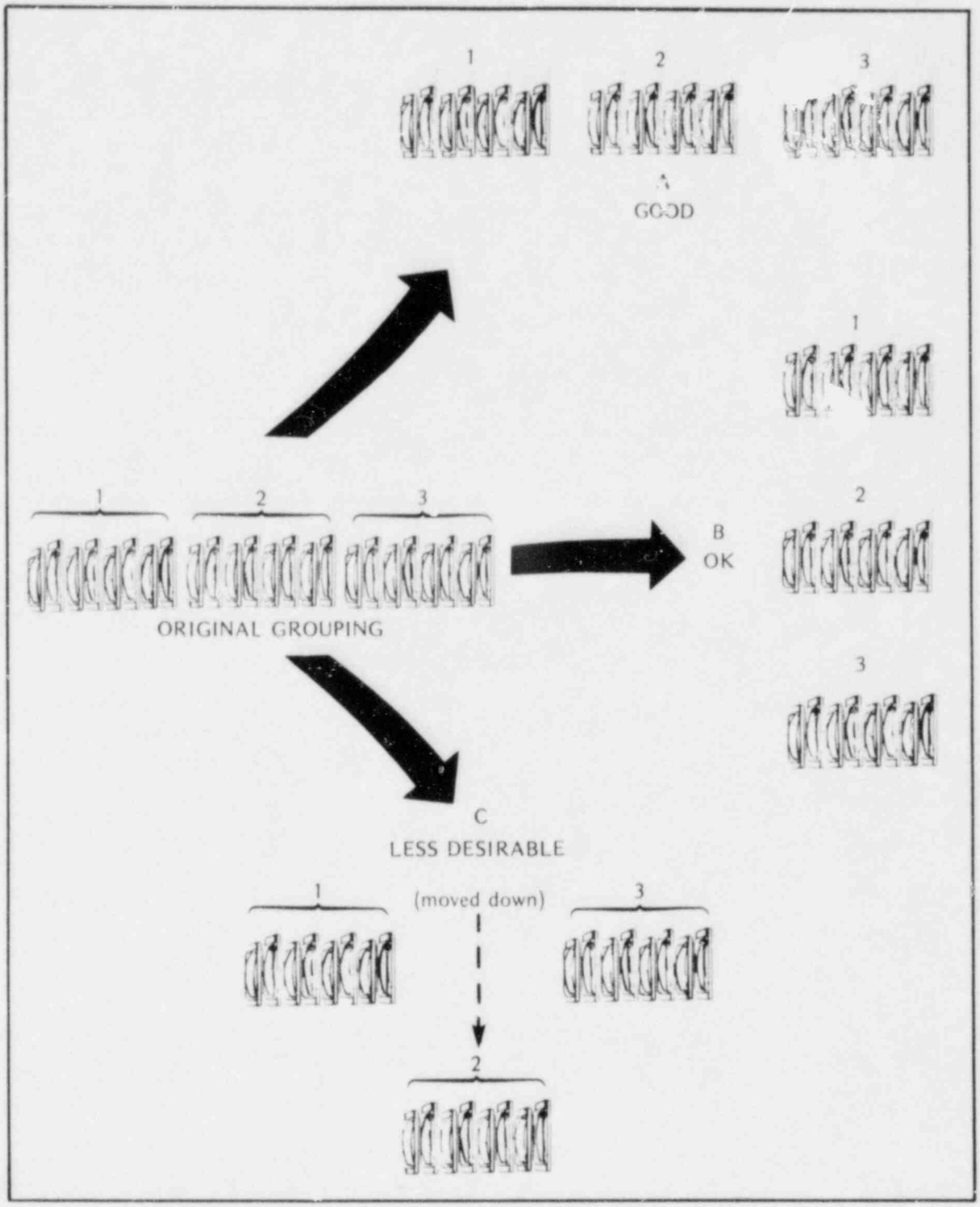


Figure 18. Example problem showing how a display grouping that is too close together can be regrouped for easier identification.

PROBLEM: A difficult-to-reach switch (X) must be moved.

EXPLANATION: Among the two alternatives shown, the top one is preferable since the control being moved is still easy to discriminate from the array located near it (A through E). But in the other example, moving each control one position to the right could result in massive negative transfer, X being perceived as A, A as B, etc.

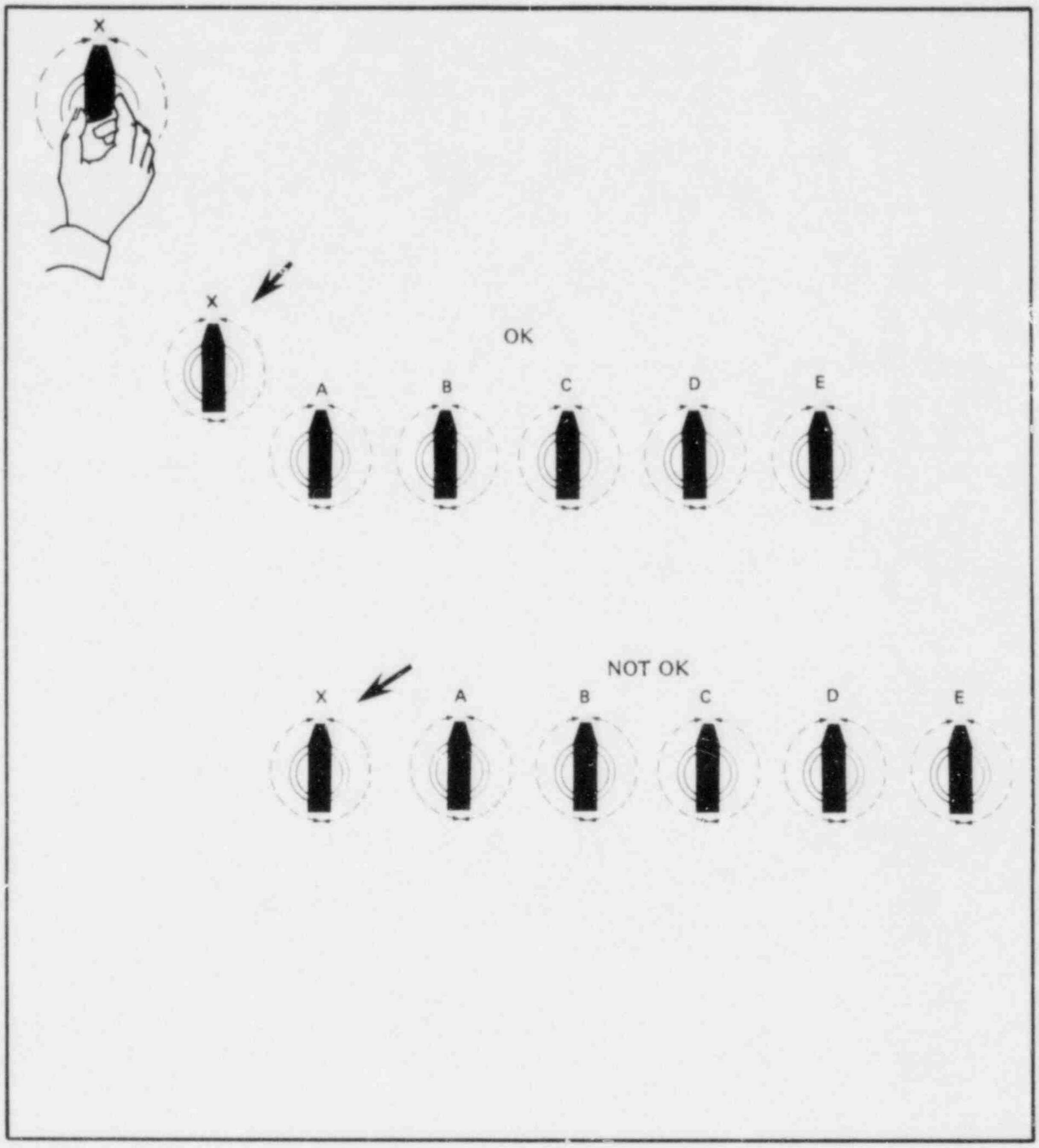


Figure 19. Example problem showing how a difficult switch to reach (X) can be repositioned in a way to avoid operator error.

PROBLEM: A mirror image needs to be corrected, but extensive redesign is not possible.

EXPLANATION: If the actual mirror image configuration cannot be changed, color coding will reduce the likelihood of negative transfer between the arrays by reducing the possibility of an operator confusing the two arrays.

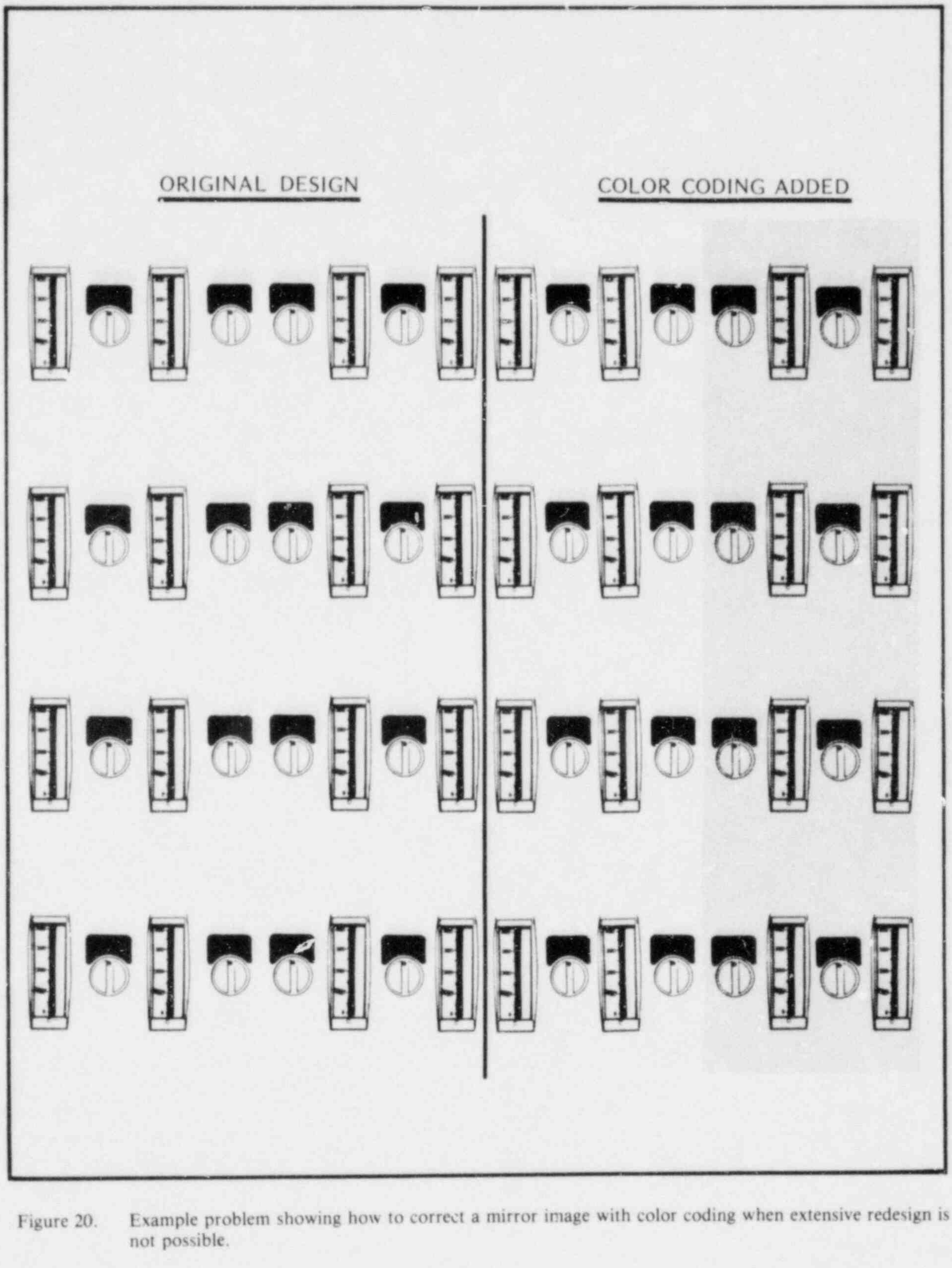


Figure 20. Example problem showing how to correct a mirror image with color coding when extensive redesign is not possible.

LITERATURE REVIEW

Introduction

The purpose of this review is to describe and consolidate new and tested information about transfer of training now being used by designers engaged in the modification of nuclear power plant (NPP) control rooms. In order to achieve this goal, principles of transfer have been extracted from the literature and evaluated for relevance to the question of equipment redesign. Since very little research bearing directly upon the redesign question has been conducted, the literature discussed in this review was selected from theoretical and human performance areas deemed by the authors to be most applicable. Reviewing the theoretical literature serves to reveal and clarify conditions, operations, and processes which may be important in determining the nature of transfer in a variety of situations. The human performance literature provides a degree of reality testing; in that it helps to define the limits between laboratory research and actual work situations. The present review is useful in assessing those operations and phenomena that have been isolated under laboratory conditions in respect to their pertinence to the complexities of more realistic performance situations.

The main subsections of the review are Background, Literature on Transfer Processes and Phenomena, Literature on Human Performance, and Summary and Discussion. The background discusses the historical trends, basic theoretical positions, and methodology associated with transfer research. The discussion of transfer processes covers a number of operational approaches to transfer (e.g., predifferentiation; variation in learning). The human performance discussion deals with transfer research in such areas as motor skills, controls/displays, and simulation. The summary and discussion integrates the literature findings and discusses the question of application.

Background

Interest in transfer of training has existed in one form or another for centuries. Teachers and scholars always have wondered how much influence specific learning experiences have upon students' ability to master totally new material. In more recent times, managers in industry, government, and military settings have become increasingly concerned with the relationship between what is learned in training and actual performance on the job. Researchers have addressed the transfer problem across a wide spectrum of theoretical and methodological approaches. One of the earliest recorded studies was that of James (1890), who analyzed the effects of memorizing one work of poetry upon the learning of a second; he found no facilitative effects. As discussed by Hogan (1978), a number of researchers studied the problem of improving memory through training, but they found no transfer via improved memory functions. In general, the notion that the mind can be strengthened in discernible ways through memorization tasks received little confirmation. The emerging view was that transfer depended upon the existence of common elements shared by the two tasks (Sleight, 1911; Thorndike & Woodworth, 1901). The "common-elements" approach was rejected by Judd (1908), who argued that principles abstracted from an original training task are what transfer to a second one. The common-elements and principles-learning theories to some extent foreshadowed the later research in "specific" and "nonspecific" transfer, respectively.

As Ellis (1969) pointed out, by the 1930s approaches to transfer had shifted, particularly in respect to the level of analysis. Such researchers as McGeoch (1931), Yum (1931), and McKinney (1933) performed detailed studies on the question of similarity and transfer, and the trend from that point on generally has been to uncover transfer processes via standardized experimentation in which well-defined variables are manipulated. A tremendous amount of such experimentation has been conducted, encompassing a variety of approaches in both animal and human research. For example, Spence (1937) and Harlow (1949) performed animal research dealing with transposition and learning sets, respectively. Their findings and conclusions influenced the theories of those performing transfer research with human subjects. Academic transfer researchers, who had largely adopted the use of verbal materials, have approached transfer from such perspectives as stimulus-response associations, mediation, attentional processes, and cognition. The data of Spence (1937) and Harlow (1949), among others, contributed greatly to the conceptualizations that have been developed in the theoretical arena of human transfer research.

By no means has all transfer research been conducted with verbal materials or within the framework of theory-building. Some experimenters have employed sensory stimuli and/or motor response options in laboratory settings, and a great deal of transfer-of-training research has been conducted in the area of simulation. Studies in simulation rarely are dictated by theoretical questions but rather by the nature of training problems confronted by the users of actual systems, especially military ones. Thus the experimental manipulations and designs employed are constrained by both the nature of the problem at hand and the practicalities associated with limited subject (S) populations and expensive equipment. Nonetheless, such research does serve to test the generalities of those principles abstracted from the more basic theoretical research.

A short discussion of the materials, designs and paradigms used in laboratory transfer research will help to bring the subsequent review topics into focus. The use of verbal materials, of course, evolved from Ebbinhaus's (1885) development of "nonsense syllables," often referred to as CVCs (consonant-vowel-consonant). He originally employed them in serial learning tasks, but verbal learning studies in the area of transfer typically use CVCs in "paired-associate" tasks. In such tasks, Ss (or subjects) are required to learn the associations between a list of CVC stimuli and designated CVC responses (Rs), although other types of response modalities sometimes are used. The advantage of paired associates is that they allow independent manipulation of stimulus and response characteristics, as well as their associative properties. Thus, such things as stimulus discriminability and response complexity can be varied systematically without altering the overall nature of the task. CVCs also have the advantage of low extant meaningfulness to Ss, which reduces the influence of extra-experimental variables. In this respect, however, researchers such as Glaze (1928) and Noble (1963) introduced measures of meaningfulness, along with associated lists, which have been evaluated on the dimensions used, allowing experimenters to independently manipulate CVC meaningfulness given they accept the meaningfulness dimension used as reasonable.

Transfer experimental designs could be considered special cases of within-subjects design; they are intended to demonstrate sequence effects rather than eliminate or counter balance them. For some period of time the most frequently used design was that shown as follows:

	Task 1	Task 2
Experimental Ss (E)	A	B
Control Ss (C)	—	B

This was used to measure specific transfer factors related to shared characteristics of the two tasks. However, since Task 1 learning could produce nonspecific transfer as well, a more acceptable design is the following:

	Task 1	Task 2
E	A	B
C	Irrelevant training	B

The irrelevant learning task for C in theory will produce as much nonspecific transfer as that of the experimental condition, thus controlling for it. The addition of a third group, receiving only Task 2(b), would be necessary for the evaluation of nonspecific transfer in C.

Various paradigms are employed in transfer research, but they often tend to be confusing for two reasons. First, the tasks, as well as the stimuli and responses, are designated with capital letters. Second, the paradigms represent the *relational* aspects of the tasks, not the sequential. For example, in a positive transfer paradigm, such as the one below,

	Task A	Task B
E	A-B	A′-B
C	A-B	C-D

the two tasks for E share identical responses and similar stimuli, while for C both the stimuli and responses are dissimilar. However, it is the second, not the first task which is the same for both groups, allowing for unconfounded evaluation of transfer. In the discussion of transfer experiments, the convention often is to simply describe the experimental group while the nature of the control is left understood. For example, A-B, A-K could be used to represent a negative transfer paradigm in which experimental Ss are transferred to a task in which the response, but not the stimuli, are dissimilar; or in A-B, A-B_r the transfer task involves the re-pairing of stimuli and responses within the same list. Many other variations exist, describing a variety of generic experimentally manipulated task relationships.

Literature on Transfer Processes and Phenomena

The ensuing discussion of transfer of training is organized around the operational approaches that have been used in studying transfer processes. Although various theoretical approaches to transfer also exist, the correlation between theory and empirical research is not sufficient to allow easy classification of studies by theoretical orientation. Many studies lend themselves to different theoretical interpretations, and such interpretations of course will be discussed but they will not be used to group studies. Finally, classification by type of operation is more appropriate to the review's purpose, providing a foundation for the discussion of transfer in an actual operational setting.

A few comments about the nature of transfer research over the past 30 to 40 years are appropriate at this point. First, while early research often was directed at the question of how to create positive or negative transfer, transfer research has increasingly been conducted with an eye toward the discovery of underlying processes. That is, transfer paradigms frequently are used as tools for the study of basic learning processes rather than as a means of uncovering ways of affecting transfer. Nonetheless, the resultant data have definite implications for situations where transfer per se is the topic of primary interest. Second, the theoretical interests among transfer researchers have become increasingly cognitive, although strictly S-R and mediational theory are by no means obsolete. Most experiments are not true tests between broad theoretical approaches and, depending upon experimental circumstances, a variety of transfer processes may exist as reflected by the general acceptance of specific and nonspecific transfer phenomena. Third, while some of the motor skill research is of theoretical interest, it will be discussed in the next section rather than the present, primarily because the response modalities approximate more closely those of applied settings.

Operational Approaches to the Study of Transfer

The variables and experimental operations discussed below constitute the approaches to experimental transfer research that have been predominant in the area.

Stimulus and Response Similarity. This refers to the similarity between the stimuli and/or the responses between different tasks. The question undoubtedly evolved at least in part from the importance which Thorndike and Woodworth (1901) attached to "identical elements" in different learning tasks. A more analytical approach is to examine the similarities between the specific stimuli and responses employed in the two different tasks.

The bulk of the interest in the subject has revolved around Osgood's (1949) "transfer surface" represented by his model, which proposed that the degree and type of transfer depends simultaneously upon the similarity of both the stimuli and responses used in the two tasks. He indicated that an interaction exists between stimulus and response similarity, and transfer cannot be predicted from knowledge of only one.

Basically, response changes tend to have a more dramatic effect upon transfer, with the combination of low intertask response similarity and high stimulus similarity producing the greatest negative transfer. Maintaining high response similarity will generally produce positive transfer, the degree depending upon the similarity of the stimuli in the two tasks. Overall, with high response similarity, increases in stimulus similarity will increase positive transfer. With dissimilar responses, increasing stimulus similarity will produce increasing negative transfer.

As Ellis (1969) and Clark (1972) pointed out, a number of experimenters (Bruce, 1933; Gibson, 1941; Wimer, 1964) have to varying degrees confirmed the basic findings derived from the transfer research. However, the model has some definite problems. One is that of defining similarity. For example, Ellis and Feuge (1966) stated that stimuli can be ordered along continuous dimensions. But others take the discrete-elements track, which is operationally easier to assume in verbal learning studies, in which distinct CVCs typically are employed. However, pre-experimental experience also can have significant effects upon the perceived similarity of stimuli, which complicates the issue even further. Common or uncommon associations between dissimilar words, for example, can endow them with increased similarity in meaning, which leads to a second problem. How can similarity between tasks be defined outside of the laboratory? Are we talking about similarity in meaning, procedures, conceptual content, or physical characteristics? This then leads to the third point: Many experiments have revealed that transfer cannot always be attributed to physical elements that are specific to both tasks (see Kausler, 1966).

Predifferentiation of Stimuli. The previous discussion refers to the question of similarity *between* the elements of different tasks. However, the question of similarity among elements *within* tasks poses a somewhat different problem. It is generally accepted that stimulus discrimination training will transfer to a task involving the same stimuli. However, relative effects of different stimulus pretraining tasks and the related processes involved in transfer to another task are of great interest.

Arnoult (1957) was the first to fully define the issue. He pointed out that contrary to the predictions of Osgood's (1949) model, some research showed that positive transfer sometimes occurred in situations in which the original stimuli were paired with new responses in transfer. Arnoult concluded that original training somehow "predifferentiates" the stimuli, making them more discriminable. Arnoult discussed the kinds of predifferentiation tasks employed to test various hypotheses about the underlying process, and summarized the theoretical explanations evolving from such research. In short, he described how predifferentiation tasks vary in respect to both the relevance of the stimuli and responses to the transfer task and to the experimental operations performed in pretraining. He also discussed various hypotheses that account for positive transfer in predifferentiation experiments: acquired distinctiveness of cues, reduction in intralist generalization, increased meaningfulness, attentional responses, and performance set. The issues are quite complicated and are discussed at length by Ellis (1969). He points out that *Relevant-S* (stimulus) research has generated a great deal of theoretical controversy about the nature of predifferentiation. While the issue in part boils down to the question of the perceptual discrimination of pre-existing stimulus elements versus the learning of new mediational responses, there are problems of methodology, definition, and conceptual clarity that cloud the situation. Ellis and Muller (1964) studied some of the methodological problems in detail, and numerous other studies present the various theories, which have been only lightly touched on here (Gibson, 1940, 1953, and 1963; Gibson and Gibson, 1955; Goss, 1953; Hake and Ericksen, 1955; Miller and Dollard, 1941; Postman, 1963).

Response Difficulty. The previous discussion deals with the stimulus-learning characteristics of learning and transfer. In predifferentiation studies, subjects learn something about distinctive features of stimuli and/or attach mediating responses to stimuli; this is what transfers to the second task. However, as Osgood (1949) implied in his model, it is equally important to look at the response side. Logically, if high between-task response similarity increases positive transfer, one would expect that increasing the difficulty of such responses would further facilitate transfer. In other words, if such responses have already been learned in the pre-task, all that remains to be done is associate them (or similar responses) with the transfer-task stimuli. Jung (1965) found that decreasing the meaningfulness of responses (hence increasing difficulty) does in fact increase positive transfer.

That response learning is a somewhat independent phenomena has been well established by Underwood, Runquist, and Schultz (1959) and McGuire (1961). Although these studies dealt primarily with acquisition rather than transfer, the potential impact of response strength upon transfer performance is implicit in their findings, and this is particularly relevant to the discussion following.

Amount of Practice. Experiments in which the amount of practice on either first- or second-list learning using the A-B, A-C (negative transfer) paradigm have yielded provocative data regarding the nature of both acquisition and transfer. While increasing practice on the initial task up to a point produces increasing negative transfer, additional practice (overlearning) often reverses this effect and may even produce positive transfer. Mandler (1962) presented a cognitive explanation for this phenomena. He says that with first-task overlearning, a representation of the responses forms (response analogue) and subjects are more or less able to put this representation aside, effectively reducing interference with the responses to be learned on the second task. Jung (1965) presented both methodological and theoretical arguments against such cognitive interpretation, but, as will be discussed shortly, cognitive explanations have a definite place in this area.

The problem of second-list practice upon negative transfer is equally interesting. Barnes and Underwood (1959) varied the amount of training that subjects received on an A-C list following training on A-B. Following A-C training, subjects were given a test in which they were asked to recall both or either of the responses that had been paired with each stimulus. The data showed that with increasing second-list practice recall of A-C items improved while recall of A-B responses correspondingly decreased. Since subjects had been asked to recall items from *both* lists, decrements in the recall of A-B responses were attributed to unlearning rather than response competition. Unlearning is analogous to loss of associative strength, or extinction—a process which Melton and Irwin (1940) had desribed earlier and labeled "Factor X." In respect to the problems associated with negative transfer, the important point is that increasing the amount of practice on the A-C list seems to virtually erase first-list responses, thereby eliminating the possibility of errors due to intrusions from the original list.

Conceptual Task Similarity. As mentioned earlier, Judd (1908) believed that an important element of transfer in second-task learning is the application of principles learned in the prior task. This is considered one element of nonspecific transfer, the other being warm-up, to be mentioned later. Among the early systematic demonstrations of nonspecific transfer were the animal studies of Spence (1939) and Harlow (1949), who worked with tranposition and learning sets, respectively. While Spence's interpretation of his findings was decidedly S-R, Harlow's was a more cognitive, learning-to-learn explanation. In the area of human learning, Duncan (1953) performed research involving the transfer of subjects between tasks in which they had to make a variety of level movements to different light stimuli. The subjects showed positive transfer in all conditions, even when the tasks were quite dissimilar. In verbal learning, Postman and Schwartz (1964) found positive transfer when both the type of task (serial versus paired associate learning) and class of materials were varied, transfer being independent of the class of materials.

Some of the more interesting data regarding conceptual task similarity may be found in the concept-learning literature. Concept-learning involves subjects sorting multi-dimensional stimuli into different response categories, the logical basis for the assignments being predetermined by the experimenter. Kendler's (1961) work pointed in the direction of cognitive explanations for some transfer phenomena. He found that on reversal-shift tasks adult subjects transferred more rapidly when all previous category responses were reversed; when some of the previous category assignments remained the same (extra-dimensional shifts), transfer was less rapid. Although a mediational explanation was offered for correct dimensional selection, an S-R position cannot explain the advantage of reversing all responses. The use of strategies and rules by subjects in concept problems has become a common approach to explaining the positive transfer often found in concept studies. Bourne and Guy (1968) trained subjects on problems in which the solution was based upon bidimensional rules that can be defined in terms of truth-table logic. The authors found a great deal of inter-rule transfer, the degree of which was determined largely by the logical relations between the rules.

Royer (1979) discussed other cogntive approaches which to varying degrees are relevant to the question of transfer. These approaches embody such notions as schema learning, hierarchically arranged mental structures, and various retrieval processes. The predictive capabilities of such theories are generally very limited at the present time, but they do point out the importance of nonspecific factors in transfer.

Other Variables and Phenomena. A number of other experimental operations have been performed in order to evaluate their effects upon transfer; the following are among the more prominent. Warm-up has been the subject of a number of studies, and Heron (1928) and Snoddy (1935) demonstrated this effect conclusively in motor learning and verbal learning, respectively. Warm-up as described by Hogan (1978), comprises postural and sensory adjustments that occur during the learning of a task and help to heighten performance on a second task that is contiguous in time. Such effects dissipate during rest intervals. Task variety is another variable that generally appears to produce positive transfer. Such researchers as Attneave (1957), Dukes and Hovland (1959), Duncan (1958), and Paul and Noble (1964) have demonstrated this effect in a variety of learning situations. Another approach to task variations is that of relative task difficulty. However, as Ellis (1965) explained, there are many inconsistencies in the data, resulting at least in part from the problems inherent in trying to define exactly what difficulty is.

Finally, one variable often assumed to create negative transfer is stress. Although Hebb (1955) and Lindsley (1952) described the apparent U-shaped relationship between arousal level and performance, there is little data that clearly define the influence of stress upon either original learning or transfer performance. Lazarus, Deese, and Osler (1952) pointed out that stress can inhibit verbal learning performance in the laboratory, but in military aviation settings the evidence is not conclusive. They also discussed the difficulties involved in arriving at a concensus of what stress is, how it can be produced, and how it can be measured. In respect to transfer per se there is very little data. While one can assume that inducing stress during acquisition might inhibit learning and thus limit the amount of learned material to be transferred, the really interesting question pertains to the effects of inducing stress during transfer performance. Little evidence exists at this time suggesting negative transfer in such a situation.

Transfer Effects and Human Performance

In the laboratory, positive and negative transfer effects are readily demonstrated. However, the impact of negative transfer, in particular, upon operational systems may not be apparent. The following quotation from a National Transportation Safety Board accident investigation report (*Aviation Week and Space Technology*, 12 April 1982) clearly illustrates the reality of possible transfer effects in operational settings.

> "Contributing to the accident were the captain's lack of recent experience in the B-727 aircraft and a transfer of his DC-10 aircraft landing habits and techniques to the operation of the B-727 aircraft." (p. 124).

This example, though not from an NPP control room exemplifies the basic condition necessary for negative transfer, same/similar stimulus pre-post but different responses pre to post. In the example the landing procedure and visual scene are similar, but the response envelope, e.g., control feel, system responsiveness, was different enough to create a negative transfer effect. An important point of this example is that the captain had minimal training between 3-1/2 years of DC-10 flying and taking over the B-727. Also, he had not flown a B-727 for over two months on the day of the accident.

In short, positive and negative transfer effects are possible in real world settings. The purpose of this section of the literature review is to examine what has been learned about transfer as it effects human performance in the real world.

Since the topic of this project was NPP control rooms there was some hope that experiments would be available in closely akin settings. None were found; therefore, the literature on transfer, primarily from aerospace and psychomotor skill research was used. This research is organized around four questions.

Does Transfer Occur in Applied Settings? As shown in earlier parts of this section, transfer research dates back to the late 1800s. Attempts to measure transfer in an applied sense were sporadic until World War II. Then the time, cost, and safety factors inherent in flight training brought renewed interest in simulation and the resulting transfer of training.

Early Research—In 1950 Mahler et al., reviewed operational flight trainers (OFT) in the Navy. He found that positive and negative transfer effects were clearly demonstrated in many laboratory studies but were not clear in military/operational settings. Evaluations of OFTs (simulators) were contradictory. Some positive, some zero, and occasional negative transfer effects had been found. The major reason for these inconsistent results are methodological difficulties:

- No control groups
- Short duration or use of OFT
- Very small sample sizes
- Inadequate criterion measures
- Little replication.

The Middle Years – Eighteen years later Valverde (1968), Grimsley (1969a), and Bernstein and Gonzalez (1971) reviewed use and evaluation of flight simulators. Several of the same methodological problems were still evident, i.e., criterion measures were usually judgmental, subject matching did not work well (randomizing was better). Because of these weaknesses there were still disparities between results. However, several technique problems had been overcome.

Generally, it was clear from the several dozen studies reviewed by these authors that there was substantial positive transfer from procedural or operational flight trainees to actual aircraft. The results of Payne et al., (1954) exemplify simulator results. Comparing control (all flight, no simulator) and experimental (simulator substituted for much of real flight training) groups, they found that simulator-trained subjects (a) required 61% fewer trials in aircraft; (b) made 74% fewer errors in-flight; and (c) demonstrated overall superior ability to handle the plane in approach and landing.

Use and evaluation of simulators to this point revealed that transfer varies considerably on the training conditions. Specifically on the type and content of training, or the conditions being simulated and on the quality of instruction. Of particular importance was the finding that the instructor played a vital role in determining the degree of transfer from a simulator to aircraft. The magnitude of this finding is suggested in the formula of Muckler et al., (1959) that:

simulator fidelity x instructor ability = transfer.

In other words, simulator fidelity and instructor capability are equally important in that they can be traded off to achieve transfer of training.

Positive transfer could be achieved and some of the variables controlling transfer were being identified. However, these reviews reinforced the earlier finding of Mackie and Christensen (1967) that R&D results still did not provide principles very useful for trainer or device designers.

Recent Findings – During the 1970s, many additional transfer studies were performed. Advanced aircraft and cost made simulation a necessity for training. Correspondingly, additional research was performed. In reviews of that literature (cf., Michelli, 1972; Caro, 1973 and 1977; Blaiwes, Puig, and Regan, 1973) the evidence for highly positive transfer from simulators to aircraft is methodologically defensible and quite convincing. Some general conclusions which can be drawn from this research include:

- Different kinds of flignt tasks have different transfer effects—the most positive transfer comes from simulation or procedural and instrument flying tasks; transfer lessens as more complex maneuvers are attempted.
- Simulators result in considerable time, safety, and cost savings.
- Simulators provide a training mode for a diversity of emergency situations.
- Training programs, including instructors, are a critical element in achieving positive transfer. Far more emphasis needs to be placed here when considering transfer effects.
- The basic principles of transfer apply in the flight simulator situation.

Several issues related to simulator evaluation have been addressed and are relevant to the control room. Since prediction of positive or negative transfer is theoretically related to the similarity of stimuli and responses (S-R) in the pre (training) and post (actual flight) conditions, S-R identification becomes critical. Caro (1970) developed a method of locating S-R in the operational setting and comparing them to the S-R of simulators to determine the degree of commonality. The techniques, Equipment-Device Commonality Analysis, may be applicable to NPPs.

The measurement of transfer of training has been addressed resulting in two measures being recommended for use (Micheli, 1972). The traditional measure is percent transfer and is given by:

$$\% \text{ transfer} = \frac{Zc - Ze}{Zc} \times 100$$

where:

Zc = performance or time required on the operational (post) task by the control group

Ze = the same measure for the experimental group.

This, in essence, is the percent difference between a control group who does not receive simulator training and an experimental group which does receive simulator training. A more recent measure developed by Povenmise and Roscoe (1971) is the Transfer Effectiveness Ratio (TER) and is:

$$\text{TER} = \frac{Yc - Ye}{Xe}$$

where:

Ye = time to proficiency in operational (post) task by the control group—no simulator

Yc = the same measure for the experimental group

Xe = training device hours received by the experimental group.

This formula accounts for the amount of time spent in the simulator; a variable not considered in a transfer but one of importance in determining effectiveness.

In summary, positive transfer has been convincingly demonstrated in operational training settings. While negative transfer can and has been found, enough is known about it to avoid such effects. There is not enough known about transfer to give concrete design principles to device designers.

How Much Device Fidelity is Required for Positive Transfer? The simulator reviews referenced above discuss the fidelity issue. This issue is important because training effectiveness breaks down into amount of fidelity, which in turn translate into device complexity and cost, times, and amount of transfer. The higher the transfer achievable with the least costly training device and program, the more cost-effective the training.

For many years there was (and often still is) an implicit assumption made that the greater the fidelity the greater the transfer. This assumption has not held true for certain types of tasks (Adwince, 1972 and 1979). The most prominent finding is that only procedural tasks transfer as well from low fidelity as high fidelity simulators. For example, Cox, Wood, Boren, and Thorne (1965) trained men on a 92-step procedure using an equipment panel. The panel was represented by a fully functional operating panel (hot panel), a real equipment but nonoperating panel (cold panel), and line drawing of the panel. The training transfer from the line drawing simulation was equivalent to that from the cold and hot panel simulation. Similar findings come from experiments by Swanson (1954). Using hydraulic, rudder power, and fuel system control panels, he found machanic retraining equally effective with all degress of fidelity tested. An extreme example comes from Prophet and Boyd (1970) who for about $30 built a plywood and photographs mock-up of the OV-1 Mohawk cockpit, then trained pilots on aircraft pre-start, start, run-up, and shutdown procedures. The five-hour training session in the mock-up was about as effective as five hours in the cockpit of the actual aircraft. Many other examples are cited in reviews by Caro (1973 and 1977), Adams (1979), and Johnson (1978).

Thus, *low fidelity simulation is as effective in training procedural tasks as high fidelity*. This is not necessarily true for other types of tasks. Cox et al., (1954) explicitly warn that decisionmaking and psychomotor tasks may require greater fidelity. Likewise, Meister (1976) found that the more complex the task, in terms of cognitive activities, the higher the task fidelity required for team training.

These studies appear to confirm and support the concept of engineering versus psychological fidelity described by Miller (1954) and propounded by later authors (cf., Adams, 1979). Basically, the concept is that physical exactness or sameness is not always necessary for stimulus/response similarity. This is more evident in the procedural area where drawings or photos of control panels provide sufficient S-R similarity to the operational task to achieve as much positive transfer as training on full fidelity panels.

The implication of this concept for NPP control rooms is that much of the procedural training, i.e., task sequences, can be accomplished with low fidelity training. However, when system diagnosis decisionmaking tasks are trained, higher fidelity levels will likely be required. Since degree of fidelity is not readily quantifiable, further exploration using the NPP setting is desirable.

What Transfer Effects Occur with Various Types of Human Performance (Behavior)? The most thoroughly substantiated finding in the transfer of training literature is the very good transfer of procedural tasks from simulation to operation. Low fidelity is as effective as high fidelity simulation and this effect occurs with high as well as low ability, as measured by the Armed Forces Qualification Test (AFQT) individuals (Grimsley, 1969b).

More importantly for NPPs, this result has been found in a wide variety of control situations, not just in aircraft. The most recent example is given by Johnson (1978 and 1981). The experimental tasks ranged from operating sequential procedures from a master control panel in an industrial plant to normal and emergency procedures in an aircraft. Again, low fidelity simulation training transferred as effectively as high fidelity training. As part of this study, a training strategy requiring trainees to provide their own cueing and feedback from memory rather than from the instructor was effective in increasing retention of procedure following skills.

The range of settings where low fidelity was shown to transfer as effectively as high fidelity simulator training on procedural tasks is summarized in a review by Grimsley (1969a). The results were in agreement for:

- Nike-Hercules preparation and operating panels
- Basic instrument and radio range procedures in airplanes
- Pre-start through shutdown of aircraft engine procedures
- Starting-stopping procedures for tasks.

Findings were in accord for measures such as time to train, level of proficiency, amount remembered over time, and time to retrain for group and individual training.

In the cognitive domain two studies (Pfeiffer, Clark, and Danaher, 1963; and Gabriel, Burrows, and Abbot, 1965) found that visual timesharing skills in aircraft (or perceptual skills), transferred to operational tasks. In these two studies, pilots' ability to detect outside-the cockpit emergencies improved after tachistoscopic or generic simulator training. Similarly, Hopkins and Roscoe (1977) found that parallel information processing or timesharing skills transferred positively to the flight situation.

Another study more related to control room procedures than to controls/displays was by Thorndyke (1977). This experiment was a test of a method for analyzing the cognitive structures of prose. When recall of prose with two different structures was compared with recall of two prose pieces with the same structure, the changed structure interferred with recall. This finding has implications for writing NPP procedures, i.e., maintaining a common structure across various procedures will help operators recall and perhaps aid in learning and relearning.

There is also some suggestion from the literature that generic simulators are useful in training for problem-solving skills. Hunt and Rouse (1981) developed context-free troubleshooting training which was effective with power plant mechanics. Also, the Pfeiffer et al., (1963) study, mentioned previously, found that timesharing training in a generalized simulator transferred to a highly specific aircraft simulator.

Generally, there is evidence that cognitive skills, e.g., information processing, decision making, do transfer positively.

Psychomotor performance and motor skill training/behavior have been studied for many years. A variety of findings (e.g., correct learning in first few motor-skill training trials prevents errors in subsequent trials and speeds learning) are available for developing training (Welford, 1968).

This type of performance is reviewed last since it is seldom found in NPP control rooms. Various types of tracking tasks, e.g., pursuit rotor, target following in an aircraft simulator, and complex hand-eye coordination skills are not part of the control room environment. Some psychomotor coordination is required in control rooms (i.e., calibrating displays, and fine tuning temperatures, value, or rod positions) and possible transfer effects should be considered.

- Positive transfer occurs when going from part task to whole task, the greater the difference in response complexity between part and whole task, the more pre-training required (Briggs, Fitts, and Bahrick, 1958).
- Transfer from verbal response in training to a motor response in post-transfer tasks is usually positive (cf. Baker and Wylie, 1950; or Goss and Greenfield, 1938).
- Predifferentiation of stimuli, e.g., labeling of lights, facilitates later learning of motor discrimination task which uses the same stimuli (Gagne and Baker, 1949).
- Partial reversal of a motor response leads to greater response decrement than complete reversal although both lead to significant decrement (Barch 1953 and 1954).
- The more experience with a response system, e.g., airplane control stick, the more interference or decrement occurs when the response pattern is changed (Hendrick, 1971).
- Pre-experience can facilitate learning of a completely new task; new S and R (Welford, 1968).
- If control or response are uniquely and adequately coded, negative transfer is minimized when control locations are changed (Weitz, 1947).

As with other types of human performance, transfer effects generally follow the basic principles described earlier in this review. There are many variables, e.g., training, expertise, control/display, which modify those principles.

How Well are Modifications to Control Rooms Accepted? One aspect of transfer not mentioned thus far is how changes are accepted by operators. No matter what type of transfer effect occurs, if changes are rejected by operators, there will likely be performance decrement and an increase in error probability. However, if human engineered design changes are found beneficial by operators, this can only bolster the transfer from old to new.

In general, the research evidence suggests that the more controls and displays conform to accepted human engineering design criteria, the more accepted they are by the operators. Specifically, Banks and Boone (1981) found that a high and significant correlation exists between the degree to which a control console conforms to MIL-STD-1472-B and operator-rated acceptance of a particular control configuration. In essence, this study demonstrates that the closer retrofits conform to NUREG-0700, the better the design will be perceived by operations personnel as positive enhancements to control operations, insofar as accessibility is concerned.

Other studies by Boone and Banks (1980 and 1981) have indicated that plant managers (operations) and engineers will support recommendations oriented toward control room enhancements based on MIL-1472-B (NUREG-0700) if these design changes have no unintended negative transfer effects. Banks (1982) cautions that it is essential to have engineers, operators, and human factors personnel *jointly* involved in the review and design modification effort so as to minimize the types of conflicts referred to in the fourth section, "Control and Display Illustrations."

Other reports (Seminara, 1980; Malone et al., 1980) implicitly assume that negative transfer will be minimized by adherence to concepts and principles promulgated in NUREG-0700. In fact, the very nature of NUREG-0700 is thrust toward performance enhancement of nuclear control operations.

While the chance for unintended (short-term) negative transfer to occur is real, it is far outweighed by the operations benefit derived from time-tested control room improvements incorporated within an integrated systems context.

In another human engineering study oriented toward the evaluation of a hyperbaric control system (Banks, Haney, Bachrach, and Goehring, 1977), the authors concluded that retrofit activities directed toward incorporating MIL-STD-1472-B design concepts would enhance operation effectiveness, increase system safety, and allow operators greater efficiency in systems control and information extraction Again, the implicit assumption within this report is that operator adaptation problems will be both short-term and inconsequential relative to the benefits of overall enhanced system safety and operational (control) effectiveness.

Summary and Discussion

Historically, transfer of training has been of interest in both academic and applied-learning settings. While earlier views often held that rigorous training in repetitive tasks strengthens or develops one's memory in some fashion, somewhat different views prevail today. In general, two fundamental categories of transfer phenomena are widely recognized: specific and nonspecific transfer. Specific transfer refers to those phenomena which are related to the physical or procedural commonality of two tasks. Nonspecific transfer encompasses a number of cognitive processes and warm-up effects. Different experimental paradigms have been developed both to separate the effects of specific and nonspecific phenomena and to provide a tool for the evaluation of the learning processes which underlie both positive and negative transfer.

In the area of theoretical research a great number of operational approaches have been employed in the study of transfer. Among the more interesting variables which have been studied are stimulus-response similarity, predifferentiation of stimuli, response difficulty, amount of practice, and conceptual task similarity. Such variables as stress, task variety, and warm-up also have been employed in transfer research. Among the conclusions which apply to positive and negative transfer, a few are particularly deserving of mention. In respect to negative transfer, changing the pre- and post-task responses seems to have the greatest decremental effect upon second task performance, although concurrent changes in stimulus similarity can reduce negative transfer. On the other hand, decreases only in stimulus similarity, at least up to a point, often produce little reduction in positive transfer and no negative transfer. On the positive transfer side, it appears that a number of variables and learning phenomena contribute to transfer of training. Response learning, stimulus discrimination, and large amounts of first- or second-task practice all appear to increase positive transfer and/or eliminate negative transfer. With sufficient first- or second-task practice, for example, any interference from the initial task seems to virtually disappear. Also, the conceptual relationsnip between tasks seems to be critical, and positive transfer often is found in situations where the original and transfer task are physically quite dissimilar. Finally, there seems to be little evidence regarding the influence of stress on transfer performance.

In regard to the human performance research, the data generally support the above conclusions, although the amount of experimental manipulation has been much more limited. Motor skills research indicates that when response (control) characteristics are changed substantially, negative transfer is likely. Simulation research reinforces the notion that cognitive aspects or original learning may be of equal or greater importance in transfer performance than are physical characteristics. Even paper-and-pencil simulation, for example, can produce substantial positive transfer in some training situations (e.g., aviation).

Further Research is Necessary. In respect to the question of system modification and transfer, some caution is necessary. Although some of the motor skill work shows that control reversals and partial reversals will produce negative transfer, little apparent research has been done in situations where substantial system modification has been done. Nonetheless, it would appear that the principles abstracted from the transfer literature should be applicable to the redesign situation as well. The problem is not that of identifying new principles but one of identifying the stimuli and response characteristics of tasks which are to be modified. For example, given the complexity of NPP control rooms, one can ask the question, "*What does and does not constitute change* from the perspective of the operator?"

To address this and a variety of other issues, a matrix is shown in Figure 21. The rows and columns, respectively, represent the basic types of procedural and display/control changes possible, while the variables listed below the exhibit represent numerous task and plant factors which could be studied in conjunction with such

Transfer Research Needs for NPP Control Rooms

		Display/Control Changes				
		No Change	Enhancements	Location	New/ Different Information	Movement/ Reversals
Procedures Changes	No Change	Pre-change condition	X	X	X	X
	Modified	X	O	O	O	O
	New	X	O	X	X	O

X = primary comparisons and interactions.

O = secondary comparisons – need to be studied only if so indicated by results from primary comparisons.

List of Independent Variables To Be Studied or Controlled for the Change Conditions in the Matrix

Task characteristics–represented by matrix above

- Stimulus/response/task complexity–from very simple to full control room complexity
- Task (stimulus and response) similarity–addresses the similarity gradient problem
- Training type and amount–best ways to enhance positive and overcome negative transfer conditions; time on old, new tasks
- Task familiarity–control/display and/or procedures frequently to rarely used.

Plant system/subsystem

- Operating condition–a range from normal operating or outage (full loading) to various degrees of non-normal (e.g., out of tech. spec. to SCRAM to radiation release)
- Pressure–allotted time to perform (interacts with emergency conditions)
- Operator characteristics–inexperienced to various degrees of experience; amount of time on old task; various personnel differences
- Situational variables–time of day; hours on duty.

Figure 21. Transfer research needs for NPP control rooms.

changes. Using the matrix and the list, a great number of fairly simple research projects or experiments could be generated. The next step is to select those research projects that will quickly and efficiently address the basic question: Do the transfer principles apply to NPP control room changes? Some basic types of applicable experiments addressing such questions and requiring minimal resources immediately come to mind. A series of small-scale experiments using low-fidelity simulation (cardboard mock-ups with drawings or photos of several panels from an NPP control room) that systematically vary task characteristics (matrix cells in Figure 21 marked X) could be attempted in examining negative and positive transfer effects. Also, using the same simulation equipment, task complexity could be varied for selected cells from the matrix (three levels of complexity, e.g., one display-control link; one panel; one system. If negative transfer effects are produced, variation in response similarity (particularly full and partial mirror imaging conditions) would help to define fundamental conditions of negative transfer. Also, research on varying training conditions would help to define the training necessary to act as a countermeasure.

Research of this nature would yield a great deal of information and could be performed in a laboratory. Also, it would involve few of the methodological problems found in operational settings (e.g., limitations on experimental manipulation, the impracticality of using truly naive Ss, etc.). Additionally, a variety of innovative paradigms and designs could be employed in a laboratory setting. The obtained data then would set the stage for further research employing actual operators during simulated or (if practical) actual control room performance.

Finally, a case-study approach would be of great value in determining what the effects of retrofit actually have been in NPPs. The experiences of the different utilities could be documented, and information such as the following could be compiled.

- How modifications were made
- The basis for such changes
- The problems encountered in making the changes
- The consequences of such changes
- Photographic illustrations of the modifications.

By identifying these significant control room changes regarding displays, controls as well as their impact on training and procedures one could then develop a task taxonomy schema used for classifying and describing the impact or probable impact these changes would exert on human and system performance/risk. The resulting document would be of great value in developing guidelines for NPP human factors changes, as well as providing guidance for the solution of specific problems related to such changes.

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