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Human Factors Primer for Nuclear Utility Managers

Prepared by
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REPORT SUMMARY

SUBJECT Nuclear plant operations and maintenance

TOPICS Human factors; Human performance/efficiency; Systems engineering; Safety engineering; Training; Maintenance

AUDIENCE Corporate and plant managers / Supervisors

Human Factors Primer for Nuclear Utility Managers

Human factors engineering can increase plant safety, productivity, and availability. This primer will enable plant managers to recognize areas for improvement through human factors applications within the context of task requirements, personnel capabilities, and interface designs.

BACKGROUND Despite safety and financial constraints, utilities can achieve high levels of plant performance by managing such human factors concerns as work structure (a generic term first defined in EPRI report NP-3141), personnel motivation and training, maintenance, and control-room/workplace design and modification. Utility managers therefore need to understand the principles and rationales underlying human factors and to recognize this discipline as part of a continuing effort, rather than as the short-term solution to an immediate problem. As an extension of previous work (EPRI reports NP-309 and NP-1567), EPRI sponsored this study to promote awareness among utility management about opportunities for human factors applications.

OBJECTIVES
- To help managers increase plant performance through an understanding of the effects of human factors on plant operations.
- To help managers recognize and make decisions that will progressively improve personnel performance.

APPROACH A team of human factors experts evaluated the information needs of nuclear power plant managers on the basis of interviews conducted in a workshop setting and on surveys performed in previous research efforts. They then prepared chapters to respond to those needs. Plant representatives and human factors engineers reviewed successive drafts, recommending changes and clarifications. The final report integrated the suggestions and comments of reviewers.

RESULTS This information primer (composed in a question-and-answer format for readability) contains five brief chapters:

- Chapter 1 provides an overview of human factors engineering, discussing the objectives, methods, and benefits of this discipline, as well as some common misconceptions. The chapter presents a framework for assessing personnel performance in terms of such factors as task requirements, human capabilities, and interface designs. This framework also structures the information found in subsequent chapters.

- Chapter 2 describes factors that dictate the nature of personnel tasks: function allocations, work structure, and policies. It focuses on decisions that can improve the task requirements assigned to plant employees.

- Chapter 3 addresses decisions about personnel selection, training, and documentation that could increase personnel performance.

- Chapter 4 discusses issues of interface design. Subjects covered—design of facilities and system and support equipment—are likely to concern plant managers during the next 3 to 10 years.

- Chapter 5 presents information about resources to help plant managers initiate a human factors program and discusses staffing decisions.

EPRI PERSPECTIVE Human factors engineering provides nuclear utility managers with a program to achieve exceptionally high standards of plant performance. These high standards can best be achieved with a program that addresses selected human factors applications within a plant. This report explains all of the possible applications.

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NP-5714
Research Project 1637-5

Final Report, March 1988

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San Diego, California

ABSTRACT

This document is intended to increase managers' awareness of the effects of human factors on plant performance, help them to recognize when decisions have underlying human factors implications, provide a basis for determining how to improve personnel performance, and indicate how they can get help for planning and staffing a human factors program. To develop the document, a team of recognized human factors experts constructed lists of topics, then outlines, and, finally, chapter material designed to be responsive to the information needs of nuclear power utility managers. Successive drafts were then reviewed by utility representatives and a variety of human factors engineers. The format, style, and page layout was designed to attract interest and enhance comprehension. The document contains five brief chapters. Chapter 1 provides an overview of human factors engineering, what it is concerned with; its objectives, methods, and benefits; as well as some common misconceptions about it. Chapter 2 addresses decisions that managers might make to improve the task requirements imposed on plant personnel. Chapter 3 describes what decisions managers might make to improve the human capabilities of plant personnel. Chapter 4 completes the picture by addressing decisions related to interface designs. Finally, Chapter 5 presents information about how utility managers can get help to satisfy human factors engineering needs.

Preface

This primer was written for nuclear utility managers — people who have responsibility for making decisions about factors affecting plant personnel performance. Included in this intended audience are corporate officers, station and plant managers, department directors, and supervisors.

Nuclear utility managers have long been successfully confronting pressures for exceptionally high standards of plant performance. The public demands that safety standards unprecedented in the power industry be attained in nuclear operations. The Congress and the Nuclear Regulatory Commission try to serve this public interest. Consumers, utility commissioners, and stockholders also demand that plant operations be cost-effective. And, of course, the ever-watchful press variously represents these concerns, along with the industry's response.

But, external pressures aside, it's internal motivation — within the industry, the corporation, and the individual manager — that determines whether plant performance will be improved. It's the self improvement motivation that causes many utilities to not only respond to the letter of regulation, but to its intent as well, and to show leadership that goes beyond the limited aims of regulation. Most people in the nuclear industry agree that regulations encourage utilities to meet the *minimum* standards, not to reach for excellence.

This primer is intended to suggest how self initiated plant performance improvements can be achieved through human factors applications. Such a book is needed because few utility managers appreciate the full range of human factors applications in a plant. While some managers are familiar with certain aspects of human factors engineering, having helped determine their utility's response to NRC requirements for human factors engineering (e.g., for control room design reviews, or revision of emergency operating procedures), or being exposed to human factors applications in some other context, few recognize the full range of potential human factors applications.

The appreciation of utility managers for human factors applications is reminiscent of the fable about six blindfolded men trying to describe an elephant. You may recall that each takes hold of a different part of the beast — trunk, ear, tail, etc. — and tries to describe the whole based on a perception of one of its parts. None, of course, comes close. Using this fable as an analogy, we want to point out that the manager who's familiar with only one part of human factors engineering has no better appreciation of the whole than another person who's familiar with a different part. So it happens that some managers think human factors engineering deals mainly with structuring and managing work to achieve better efficiency. Others think it's concerned more with whether people find their jobs meaningful and rewarding. Still others think that paying attention to human factors means selecting people who are well qualified for jobs and then training them to handle all contingencies. Many think that human factors engineering applies mainly to how people get information through displays and how they manipulate controls, tools, or other objects. "What about workspace design?" you may ask, "Isn't that an important part of human factors engineering?"

The point is that human factors engineering is concerned with all of these things — and more. We hope that the information provided in this primer will expand your perspective on human factors engineering and put you at least a step closer toward taking full advantage of what's known about human performance in nuclear power operations.

Many people contributed to the preparation of this primer. In its early stages, Julian Christensen and Harold Van Cott helped identify topics that the primer should address. They also developed outlines and drafted materials, along with Dave Meister, Fred Muckler, Chuck Semple, and Battina Babbitt. In addition, Smoke Price, Mark Sanders, and Ray Riley helped review outlines and early drafts. At a workshop, members of the nuclear power community reviewed draft material and made invaluable suggestions for improvements. Throughout, EPRI management and members of the human factors sub-committee actively participated in the creation of the primer as well as providing direction and support. Joan Anderson contributed immeasurably to the conception, planning, and construction of this document. But,in fairness to all the people who helped, it should be pointed out that the Principal Investigator is solely responsible for any weaknesses that the primer may have.

Robert G. Kinkade

TABLE OF CONTENTS

Chapter 1 HUMAN FACTORS ENGINEERING 1

Section 1.1 A Conceptual Framework 2

Section 1.2 Objectives, Methods, and Benefits 9

Section 1.3 Misconceptions 18

Chapter 2 TASK REQUIREMENTS 23

Section 2.1 Decisions about Personnel Functions 24

Section 2.2 Decisions about Work Structure 29

Section 2.3 Decisions about Policies 35

Chapter 3 HUMAN CAPABILITIES 39

Section 3.1 Decisions about Personnel Selection 40

Section 3.2 Decisions about Training 45

Section 3.3 Decisions about Documents 52

Chapter 4 INTERFACE DESIGNS 59

Section 4.1 Decisions about Facilities 60

Section 4.2 Decisions about System Equipment Interfaces 66

Section 4.3 Decisions about Support Equipment 74

Chapter 5 HUMAN FACTORS RESOURCES 79

Section 5.1 Decisions about Program Planning 80

Section 5.2 Decisions about Human Factors Staffing 85

MASTER REFERENCE LIST 91

GLOSSARY 95

INDEX 99

List of Exhibits

Exhibit 1-1. Engineering personnel performance means achieving a good fit among task requirements, human capabilities, and interface designs. 1

Exhibit 1-2. The closer your plant performance is to being excellent, the more you can expect to spend to achieve improvements. 3

Exhibit 1-3. Tasks have initiating and terminating cues that are related to system and organizational requirements. 4

Exhibit 1-4. The performance of tasks depends on sensing, perceiving, interpreting, and responding abilities -- which, in turn, depend on attention and memory. 6

Exhibit 1-5. Interface designs impose specific demands on the capabilities of personnel. (Note.-- Shaded background represents conditions of performance established by facility designs and the support equipment provided.) 7

Exhibit 1-6. Examples of factors that shape personnel performance, according to the kinds of decisions that determine them. 8

Exhibit 1-7. INPO-identified root causes for 180 significant safety related events. 10

Exhibit 1-8. Sample portion of a questionnaire used to identify problems that could be overcome through changes in work structure and policies. 11

Exhibit 1-9. Sample form used in a survey to report design features that don't comply with human factors criteria. 12

Exhibit 1-10. Elements of descriptive and analytic information that can be determined through task analysis. 13

Exhibit 1-11. Sample portion of a constrained list of verbs for different classes of task behaviors. 14

Exhibit 1-12. Benefits of human factors engineering. 16

Exhibit 1-13. Human factors criteria include values for all the dimensions of control instruments shown, as well as the minimum separation required between instruments. 19

Exhibit 1-14. Sample checklist page on communications system design from a human factors guide. 20

Exhibit 2-1. Task requirements reflect decisions about how functions are allocated between personnel and equipment as well as how work is structured and managed. 23

Exhibit 2-2. Rather than total reliance on personnel or full automation, the objective of function reallocation is to achieve effective balance between personnel and equipment capabilities. 24

Exhibit 2-3. Sample functional flow block diagram showing the functions needed to control steam generator level, given a tube rupture. 25

Exhibit 2-4. Relation between specific functions and human capabilities that may be involved in performing them. 26

Exhibit 2-5. Comparative strengths of equipment and humans for performing specific functions. 27

Exhibit 2-6. Sample portion of a timeline summary for a postulated event (i.e., steam generator tube rupture). 31

Exhibit 2-7. Sample of a sociogram depicting hypothetical interactions throughout an organization during a safety related event. 32

Exhibit 2-8. General principles that can be applied in restructuring work. 33

Exhibit 2-9. Factors associated with job satisfaction are different for those associated with dissatisfaction. . . . 33

Exhibit 2-10. Relation between how far in advance planning is done and its perceived contribution to plant effectiveness. . . . 36

Exhibit 2-11. Relation between annual overtime hours worked and the percentage of personnel who reported family/social problems, decreased productivity, or concern about safe performance. . . . 37

Exhibit 3-1. Information about human capabilities supports decisions about personnel selection and training as well as needs for procedures and other documents. . . . 39

Exhibit 3-2. Plotted, the normal distribution of any ability is bell shaped, with most people in the normal range and far fewer people at either extreme. . . . 41

Exhibit 3-3. Major classification of 1,409 tests produced or revised in the last seven years. (Note.--139 tests, or 9.9%, were classified "miscellaneous.") . . . 42

Exhibit 3-4. Automated testing allows fully standardized administration, including all instructions. . . . 43

Exhibit 3-5. Variously known as, for example, instructional system design, systems approach to training (SAT), or training system development (TSD), the process of developing performance based training includes these major steps. . . . 47

Exhibit 3-6. Relative development and delivery costs for various instructional techniques. . . . 48

Exhibit 3-7. Positive transfer of learning facilities proficient performance, by negative transfer retards the development of proficiency. . . . 49

Exhibit 3-8. Relations among fidelity of simulation, transfer of learning, and costs. . . . 50

Exhibit 3-9. Symptom-based procedures prompt operators to take remedial action. . . . 53

Exhibit 3-10. Alternative ways of integrating text and illustrations. . . . 57

Exhibit 4-1. Interface designs reflect decisions about features of facilities and system equipment as well as needs for support equipment . . . 59

Exhibit 4-2. Human factors engineering asks "Will personnel be able to interpret the message quickly and correctly?" — the intended interpretation is provided in the references at the end of this section. . . . 61

Exhibit 4-3. Some of the body dimension variables that enter into decisions about facility designs. . . . 62

Exhibit 4-4. A sample link diagram for a control room, showing movements of three operators responding to a steam generator tube rupture. . . . 63

Exhibit 4-5. Conventional consoles are typically configured in modified circular, U, wing, or L shapes. Accommodating an advanced control complex within such configurations depends on how task responsibilities are assigned. . . . 64

Exhibit 4-6. The comfort zone is determined by a combination of different temperatures and humidities. . . . 65

Exhibit 4-7. System equipment interfaces profoundly affected by use of digital computers to process system data (EOF, emergency operations facility; TSC, technical support center). . . . 67

Exhibit 4-8. Panels located outside the control room that are candidates for design enhancement. . . . 67

Exhibit 4-9. Examples of common expectations about display/control relationships. . . . 68

Exhibit 4-10. Simplified portion of an operational sequence diagram, depicting task behaviors at four control room locations in response to a steam generator tube rupture. 69

Exhibit 4-11. Comparison of a panel design before and after paint, label and tape enhancements. 70

Exhibit 4-12. Sample of a schematic display with selected trend information superimposed at the bottom of the page. 71

Exhibit 4-13. Pointer, along with the numerical readout at the bottom, shows the current value in relation to high and low prealarm values; The angle of pointer inclination indicates average trend. 72

Exhibit 4-14. Lifting can be done with greater force when people can use both arm and leg muscles and objects are close to the body. Lifting capabilities are in descending order with (1) being highest. 75

Exhibit 4-15. Relationships of hearing sensitivity and voice ranges, along with typical sound pressure levels that have implications for communications. 76

Exhibit 5-1. To help achieve plant goals, an effective human factors program systematically addresses all the interrelated factors that shape personnel performance. 79

Exhibit 5-2. The industry's current interest in human factors has been likened to a "third wave" of progress. 81

Exhibit 5-3. Relationships among different aspects of human factors concern. 82

Exhibit 5-4. To facilitate required communications and coordination, responsibilities for managing a human factors program are best located in a staff position. 83

Exhibit 5-5. Relationships between design freedom and costs. 83

Exhibit 5-6. The psychological fields that should be reflected in educational credentials for human factors engineers providing various applications. 87

Exhibit 5-7. The recommended years of education and experience for varying levels of human factors applications. 88

Chapter 1
HUMAN FACTORS ENGINEERING:
For Better Plant Performance

This chapter includes three sections that provide an overview of human factors engineering. Section 1.1 defines what human factors are and provides a framework that will help managers recognize how decisions about task requirements, human capabilities, and interface designs impact on plant performance. Section 1.2 defines the objectives, methods, and benefits of human factors engineering. Section 1.3 dispels some misconceptions that can deter your utility from achieving an effective human factors program.

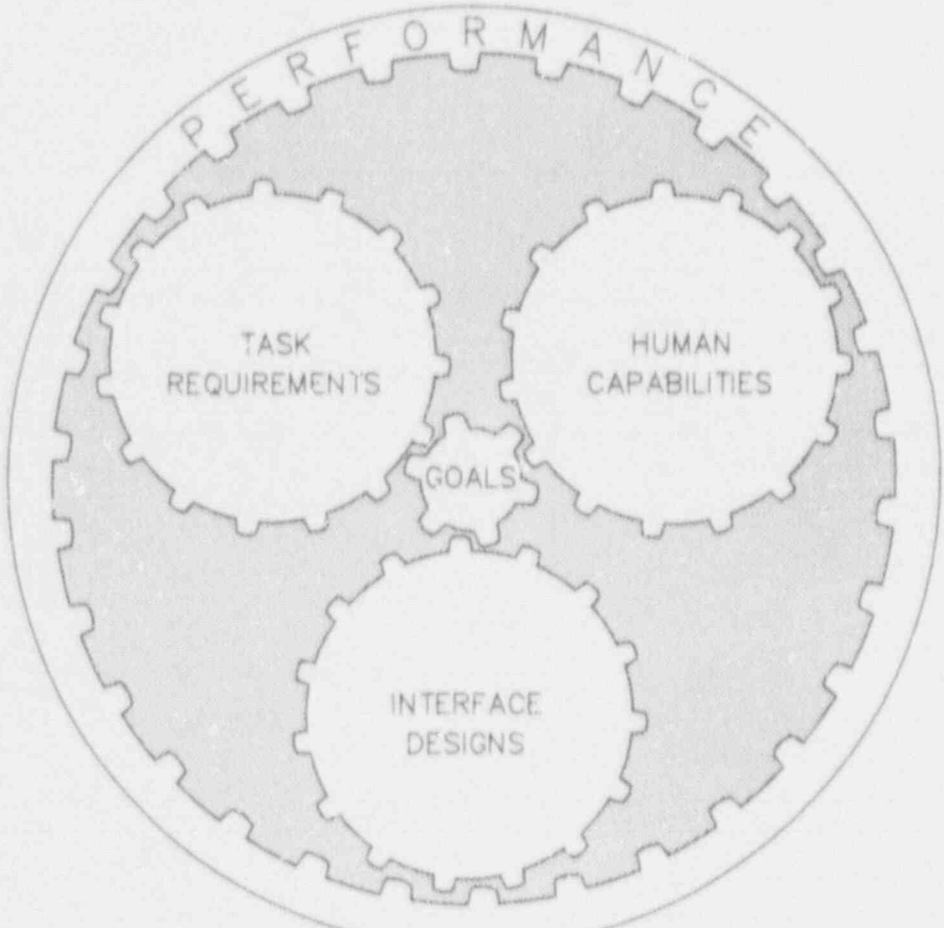

Exhibit 1-1. Engineering personnel performance means achieving a good fit among task requirements, human capabilities, and interface designs.

Section 1.1
A Conceptual Framework

Questions addressed in this section are:

What are human factors?

What plant performance goals drive decisions about human factors?

What costs and losses associated with personnel performance can't be passed on to consumers?

What are task requirements?

What progressive decisions can managers make about task requirements?

What human capabilities does task performance depend on?

What progressive decisions can managers make about the capabilities of personnel?

What's a "man-machine" interface?

What progressive decisions can managers make about interface designs?

Are all human factors in plant performance under management's control?

What are human factors?

All the variables in a work situation that interactively shape personnel performance.

For example:
- task complexity and time constraints;
- work group relations;
- human sensing demands;
- attention level, expectations, and self-confidence;
- the presence and adequacy of procedures,
- climatic conditions; and
- movement constrictions

are some of the factors that interactively determine whether personnel consistently do what's needed to help achieve plant performance goals.

Managers need a systematic way of considering human factors in the context of decisions they make. So the framework provided in this primer relates human factors to plant performance goals and management decisions about:

- TASK REQUIREMENTS *(what people are expected to do)*,
- HUMAN CAPABILITIES *(what people are able to do)*, and
- INTERFACE DESIGNS *(what they've got to work with)*.

What plant performance goals drive decisions about human factors?

Goals for plant safety, productivity, and availability — which are, in turn, related to operating costs and lost revenues.

Ways of meeting plant safety goals include not only eliminating potentials for release of radioactivity to the environment, but reducing the radiation exposure of personnel and the likelihood of their suffering injury or of equipment being needlessly damaged. Some accepted plant safety indicators are significant event occurrence, collective radiation exposure, number of personnel exceeding 5-rem annually, and lost-time accident rate.

Ways of meeting productivity goals involve increasing the efficiency, reliability, and motivation of personnel (as well as decreasing turnover, absenteeism, and tardiness). Indicators of productivity include heat rate, or Btu per kilowatt hour, and expended labor hours for work accomplished.

Ways of meeting availability goals include increasing the time the plant can operate at full power by reducing the occurrence of human errors that contribute to equipment failures or needlessly extend corrective maintenance time. Among availability indicators are forced outage rate, unplanned automatic scram occurrence, and the ratio of the power a plant actually produces to its rated capacity.

To achieve plant goals, management often has to change interrelated factors that affect personnel performance. The required level of investment in changes depends on what a plant's current performance is and on how high the utility's goals are. It doesn't cost much to get some improvement in performance that's not very good. But, more must be spent to achieve noticeable improvements in performance that's close to excellent, as shown in Exhibit 1-2. If plant safety, productivity, and availability goals are very high, they can't be achieved without making relatively high investments in human factors applications along with other improvement related activities.

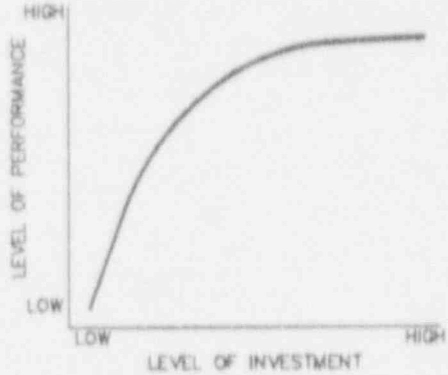

Exhibit 1-2. The closer your plant performance is to being excellent, the more you can expect to spend to achieve improvements.

What costs and lost revenues associated with personnel performance can't be passed on to consumers?

Those associated with avoidable human error.

Like utility managers themselves, consumer activists and utility commissioners are increasingly less willing to accept human error as a legitimate, unavoidable cause of plant shutdowns or extended downtime. They're more inclined to suspect underlying causes of error that are under management's control.

Recently, for example, a utility wanted to pass on the $5.4 million costs of a shutdown to its consumers. But the Public Service Commission required the utility to absorb 75% of the cost. It ruled, "Management should have foreseen the need for and benefit of instituting some form of review inspection procedure to prevent the type of human error that occurred".[1]

In another instance, a utility acknowledged the justness of an NRC fine. Its own investigation of an automatic cooling system shutdown concluded, "Unclear labeling of switches, a lack of detail in test procedures, deficiencies in training, and inadequate corrective actions led to the incident".[2]

But investments in improving personnel performance through human factors applications pay off in more ways than avoiding fines and lost revenues. Such investments enhance safety and reduce operating costs over the long run. Not only are human errors avoided, but personnel are better motivated to be productive, and help the utility achieve its goals.

What are task requirements?

All the activities personnel must perform to prescribed standards.

Tasks, or segments of work assigned to personnel, are determined by system and organizational functions. System functions dictate what and how well something has to be done to safely operate the plant. Organizational functions dictate what has to be done to plan, coordinate, and supervise system operations as well as to protect plant security and personnel health and safety.

Every task is characterized by an initiating cue and a terminating cue, as shown in Exhibit 1-3. The initiating cue indicates a discrepancy between an existing condition and a system or organizational requirement. Steps in the task have to be performed to prescribed standards. The terminating cue then indicates that the discrepancy has been corrected.

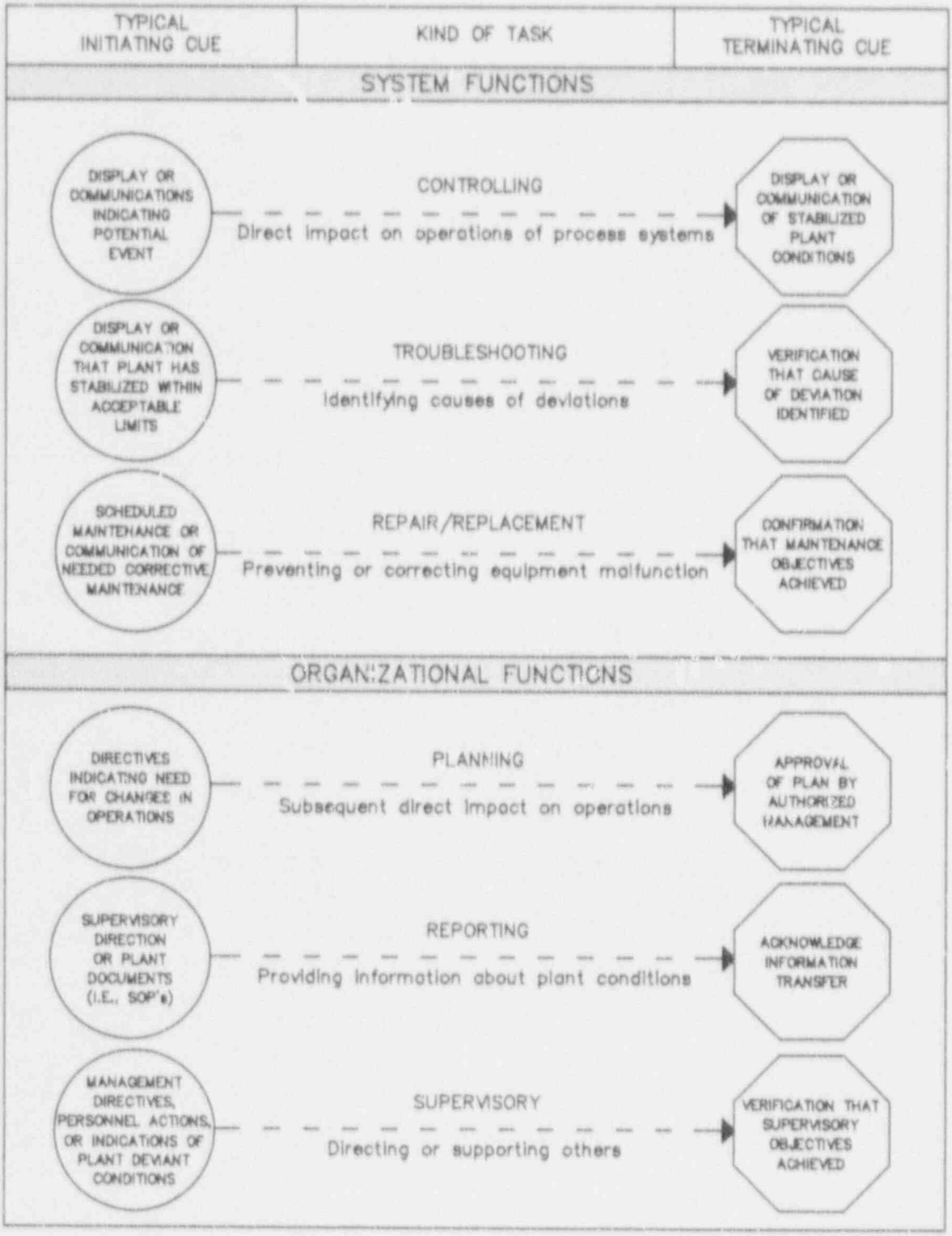

Exhibit 1-3. Tasks have initiating and terminating cues that are related to system and organizational requirements.

What progressive decisions can managers make about task requirements?

Decisions to:

- reallocate specific functions between people and equipment;
- restructure work; and/or
- institute new policies to better govern how work is performed.

With operating experience, human factors data, and advances in equipment technology as a basis for function reallocation decisions, management can achieve a better balance between the capabilities of personnel and equipment. Some task steps that are difficult for personnel to consistently perform to a required standard can be reallocated to computers and other equipment.

Management can also change task requirements by restructuring work — redesigning jobs and how they relate to others in the organizational hierarchy. That is, tasks can be redistributed among job positions so that some people aren't overburdened with responsibilities while others are idle. Work restructuring decisions can also help provide for supervision of performance, help achieve greater cost-effectiveness in training, as well as create career paths that help motivate personnel.

Management can also consider changing policies that govern how work is scheduled and performance is rewarded. Sound policies about the duration of shifts, the direction of shift rotation, and the frequency of work breaks, for example, can ease some of the problems (e.g., fatigue, lapses in attention) associated with shift work. Rewarding performance meeting explicit standards will help ensure that such performance will be repeated. Where practices that have simply evolved impose needless stress on personnel performance, the situation can often be corrected by explicit policy decisions that take human factors into account.

What human capabilities does task performance depend on?

Sensing, perceiving, interpreting, and responding capabilities — which, in turn, depend on attention and memory, as shown in Exhibit 1-4.

Capabilities are the sum of heredity and experience. Characteristics and potentials inherent at birth represent a person's basic abilities. Among these, the potentials for learning (or aptitudes) determine to what extent a person acquires certain knowledge, skills, and attitudes given opportunities. As people mature, learn, and develop inborn abilities, individual differences in capabilities become greater. Managers can capitalize on differences among individuals by selecting those with the basic abilities and aptitudes needed to perform specified job tasks, and screening out applicants who have limitations that make job success questionable.

What progressive decisions can managers make about the capabilities of personnel?

Decisions about performance based:

- personnel selection,
- training, and
- documents.

Decisions about personnel selection determine what capabilities and limitations personnel possess at the time they're hired. Screening applicants on the basis of abilities, aptitudes, and attitudes associated with training efficiency and job success reduces other personnel related costs. That is, to compensate for innate limitations of selected personnel, a utility may make high investments in training, documents, and interface designs and still suffer losses due to training attrition and job turnover.

Decisions about training determine what knowledge, skills, and attitudes personnel bring to job performance situations. Training developed on the basis of job task analysis and systematic application of learning principles helps prepare personnel to perform safely and

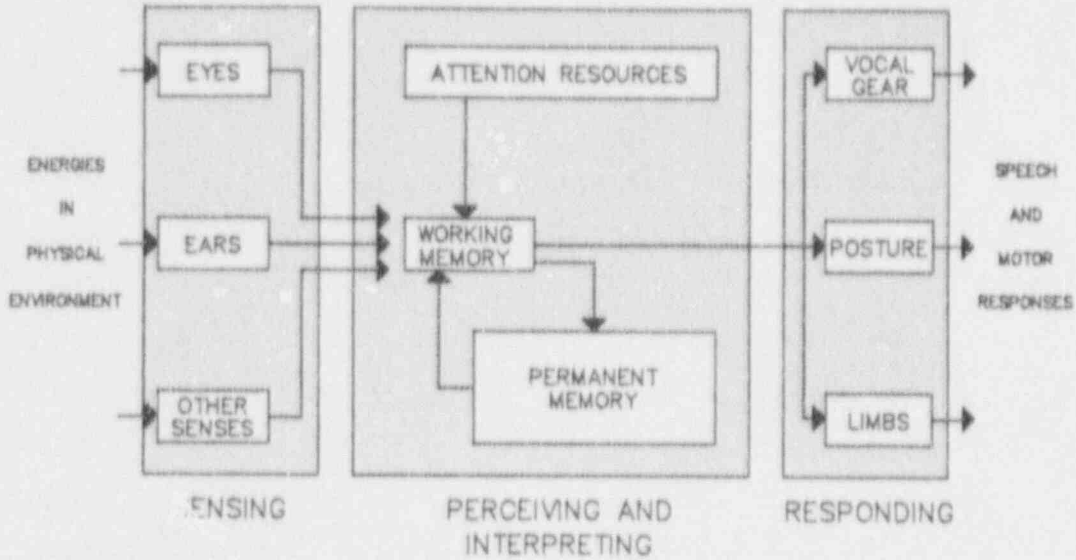

Exhibit 1-4. The performance of tasks depends on sensing, perceiving, interpreting, and responding abilities -- which, in turn, depend on attention and memory.

reliably on the job. Costly training features aren't always needed to achieve training objectives, so progressive decisions reflect the result of tradeoffs between cost and effectiveness. Decisions about documents can reduce requirements for personnel to remember and interpret information. Documents developed on the basis of task analysis and what's known about capabilities of personnel aid performance. They present task-required information in ways that are compatible with personnel capabilities and that contribute to ease of use in the actual performance situation.

What's a "man-machine" interface?

A point where energies are received or transmitted by personnel.

Interface designs reflect not only display and control features needed to exchange information between personnel and equipment, but other conditions affecting such exchanges. Interface design features include, for example, the access space provided in workspaces as well as light, heat, sound, and other environmental conditions. Devices like platforms and hoists, tools, storage containers, and furnishings also affect the efficiency and reliability of interactions between equipment and personnel.

Decisions about interface designs impose specific sensing, perceiving, interpreting, and responding demands on personnel, as indicated in Exhibit 1-5. Interface designs that are compatible with the capabilities and expectations of personnel increase performance efficiency and reduce the likelihood of error. Designs that unburden personnel of needless demands improve performance reliability. For example, consistent designs relieve personnel from the need to cope with inconsistencies.

What progressive decisions can managers make about interface designs?

Decisions about the features of:

- facilities;
- system equipment; and
- support equipment.

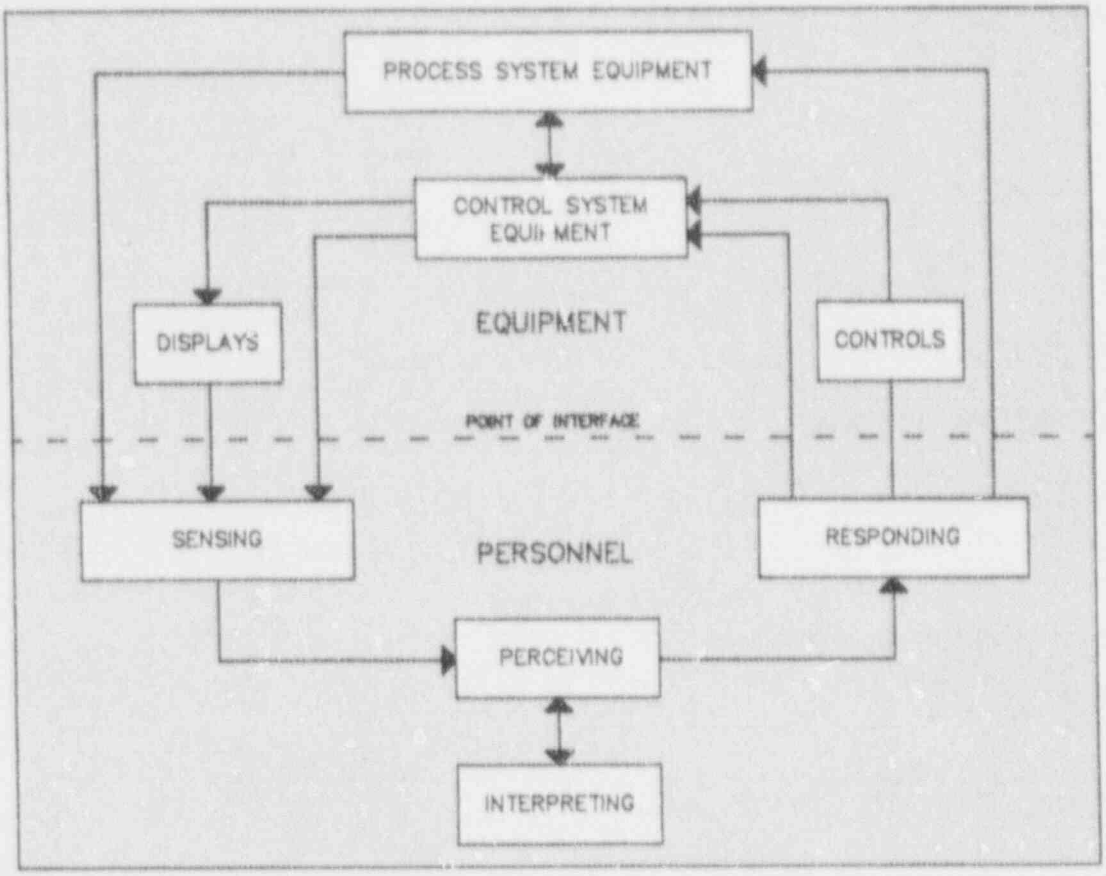

Exhibit 1-5. Interface designs impose specific demands on the capabilities of personnel. (Note.--Shaded background represents conditions of performance established by facility designs and the support equipment provided.)

Facility interface design features determine whether it's easy for personnel to locate, travel to, and reach objects and see or hear information. Progressive decisions about facility design features achieve compromise solutions to some personnel performance problems. That is, managers have to live with some design constraints that were established years ago — few things being more concrete than, for example, containment walls. Still, decisions about changes to facility layouts, lighting, and other accommodations can improve the efficiency of task performance and reduce errors as well as increase the safety, comfort, and morale of personnel.

Features of system equipment interface designs dictate how well personnel can monitor, control, and maintain equipment. Design features of displays and controls affect whether personnel attend to, clearly see, readily perceive, and correctly interpret information related to equipment operations and whether the actions they take to change equipment operations are appropriate or not. Decisions concerning advanced displays that present integrated information from numerous discrete sensors can relieve burdens on operators. Similarly, decisions about labeling and coding of plant equipment and use of performance monitoring devices can improve technician performance.

Support equipment extends human capabilities and protects personnel from hazardous environmental conditions that can't be corrected by changing facility design. Decisions about support equipment can enable personnel to meet difficult physical demands with less risk of injury. For instance, decisions about the design of protective gear not only affect the safety of personnel, but can contribute to greater efficiency and effectiveness in plant maintenance.

Are all human factors in plant performance under management's control?

To a great extent, but not entirely.

Some important factors shaping performance are difficult for managers to control. For example, managers can't be expected to assess emotional factors on a daily basis and adjust personnel assignments accordingly (although many supervisors attempt this on an informal, interpersonal basis). But, systematically improving personnel performance means leaving less to chance and relying more on enlightened choices. Human factors recommendations are intended to build in a margin of tolerance — by addressing factors that management can do something about, some of which are listed in Exhibit 1-6.

TASK REQUIREMENTS	HUMAN CAPABILITIES	INTERFACE DESIGNS
DECISIONS ABOUT PERSONNEL FUNCTIONS	DECISIONS ABOUT PERSONNEL SELECTION	DECISIONS ABOUT FACILITIES
Task complexity o information load o anticipatory demands Task criticality stress Task frequency Task time stress	Body dimensions Innate abilities and aptitudes Personal values and established attitudes Established capabilities and expectations	Traffic patterns Obstructions and distractions (noise, glare, movement) Lighting, viewing angles, and distances Level of comfort (pain, hunger, thirst, climatic conditions)
DECISIONS ABOUT WORK STRUCTURE	DECISIONS ABOUT TRAINING	DECISIONS ABOUT SYSTEM EQUIPMENT
Workload o competing demands o monotony Work group relations o authority and responsibility o group identification Interdepartmental coordination and communications requirements	Current knowledge Skill levels Attitudes reinforced during training Level of confidence Practiced teamwork	Sensing demands Perceptual demands o adequacy of coding o display/control relations Memory demands Decision making support Motor demands (speed, strength, precision)
DECISIONS ABOUT POLICIES	DECISIONS ABOUT DOCUMENTS	DECISIONS ABOUT SUPPORT EQUIPMENT
Shift schedules o biological rhythms o effects on family and social life Incentives Work breaks o attention level o uneventful vigilance Work methods	Ease of access and use Sensing demands Perceptual demands Memory support Decision making support	Ease of access and use Communications demands Motor demands Movement constrictions Physical strain and injuries

Exhibit 1-6. Examples of factors that shape personnel performance, according to the kinds of decisions that determine them.

References

1. *Washington Post*, November 28, 1982.
2. *Wall Street Journal*, December 20, 1984.
3. Swain, A.D., & Gutmann, H.E. *Handbook of human reliability analysis with emphasis on nuclear power plant application.* (NUREG 1278) Washington, D.C.: Nuclear Regulatory Commission, 1985.

Section 1.2
Objectives, Methods, and Benefits

Questions addressed in this section are:

What is human factors engineering, and what are its objectives?

What percentage of plant events is attributed to human error?

Why is human error so prevalent?

What's the source of human factors principles, criteria, and methods?

What human factors engineering methods supply useful management information?

How are questionnaires and interviews useful?

How are surveys useful?

What is task analysis, and why is it important?

What techniques are used to analyze task behaviors?

Should all tasks be subjected to comprehensive analysis?

How are test and evaluation trials useful?

What benefits have been realized through human factors engineering?

What is human factors engineering, and what are its objectives?

The systematic application of principles and criteria derived from what's known about human performance to improve operations involving people.

Human factors applications are intended to improve plant performance by increasing the safety, efficiency, and motivation of personnel; reducing the occurrence and consequences of human error; and reducing long-term operating costs. More specifically, human factors applications help ensure that personnel:

- aren't expected to perform with greater speed, accuracy, strength, or agility than they're capable of;
- have, can clearly sense, and can correctly perceive and interpret all the information needed to perform assigned tasks;
- can remember relevant information not provided in the situation;
- can easily execute required actions; and
- are unburdened of needless mental or physical demands.

In short, human factors engineering helps management get the fit that's needed among task requirements, human capabilities, and interface designs to achieve plant performance goals.

What percentage of plant events is attributable to human error?

The precise proportion is subject to debate, with experts arguing about numbers between 40 - 60%, but almost everyone agrees it's too high.

NRC attributed 44% of the events described in the 1985 Licensee Event Reports to human error. Other experts put the proportion much higher. But relatively few human errors justify filing an event report. The ones that do are like the tip of an iceberg. Human errors that occur daily may go unnoticed, but they are also troublesome and costly — some more than others.

The public has come to associate human error with catastrophic events. But errors, whether made by equipment or people, are simply deviations in performance from a specified standard. The performance of the technician, for example, who "repairs" a misidentified component may not be jeopardizing plant safety, but is needlessly extending the time some plant equipment is unavailable.

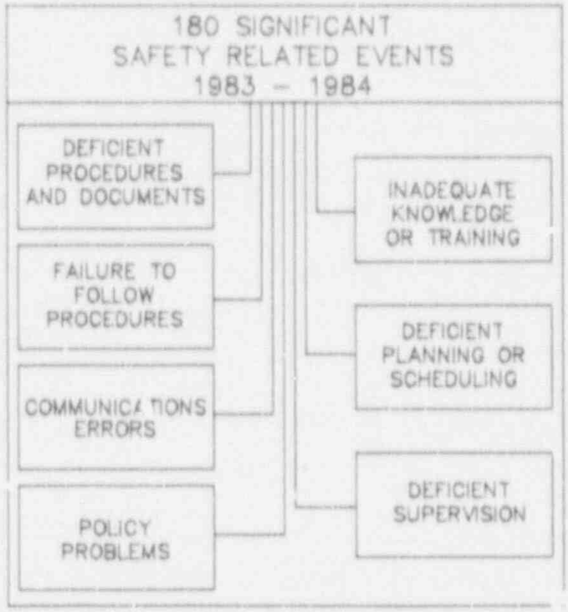

Exhibit 1-7. INPO-identified root causes for 180 significant safety related events.

Why is human error so prevalent?

Because a combination of factors, like inadequate training, deficient procedures, ineffective communications, and excessive overtime, all interactively impose demands on personnel that exceed their capabilities.

Since the days of Alexander Pope, it's been a notion in popular wisdom that "to err is human". But human errors aren't a random phenomenon, nor are they typically caused by the perversity of the people involved. Instead, they are usually induced by external "root causes", some of which are listed in Exhibit 1-7).

Human error is itself an effect, not a cause. You become convinced of this when you get beyond naming a problem and take steps toward solving it. Take a good look into any event attributed to human error. You'll probably find the human who erred is less the operator or technician in question than the designer, the program planner, or — ultimately — the manager who overlooked some human factors principles and criteria.

What's the source of human factors principles, criteria, and methods?

Diverse disciplines — including engineering, psychology, physiology, anthropometry, biomechanics, sociology, and education — as well as about 45 years of human factors research and practical experience.

Human factors engineering translates principles and research data related to personnel performance into a coherent set of guidelines or criteria. Specific recommendations that enable management to systematically improve personnel performance can then be made on the basis of such guidelines or criteria. Its methods include ways of identifying personnel performance problems, recommending possible solutions, and evaluating solutions as they're developed.

What human factors engineering methods supply useful management information?

A combination of:

- questionnaires and interviews;
- surveys;
- task analysis; and
- performance measurement in test and evaluation trials.

Each method produces information differing in nature (i.e., retrospective vs. predictive, subjective vs. objective) and detail. Collectively, they provide the information management needs to make decisions that progressively improve plant performance.

How are questionnaires and interviews useful?

For identifying factors that personnel believe affect their performance.

Questionnaires typically contain a set of questions and a range of answers for each. Personnel anonymously select from the answers provided the one that best agrees with their perception of a situation, and they may add narrative comments. Responses are tabulated, comments summarized, and some simple statistical analyses can be done (e.g., to identify significant difference among groups of respondents). Questionnaires can be used to assess, for example, feelings about the organizational effectiveness at a plant, as shown in Exhibit 1-8.

Interview methods include unstructured, structured, and critical incident techniques. In an unstructured interview, personnel respond to general questions (e.g., about the adequacy of training, documents, facilities) to identify problem areas. Structured interviews are then developed to isolate specific factors (e.g., inefficiencies in the location of workshops, tool rooms, warehouses; inadequate lighting; access problems) that degrade personnel performance.

Often used to increase the pool of events that can be analyzed for causative factors, the critical incident technique involves having personnel relate incidents that could have led to an accident or mishap had personnel not been on their toes. Once enough incidents are related, inferences can be drawn about causes from commonalities in the descriptions.

		1 TO A VERY LITTLE EXTENT	2 TO A LITTLE EXTENT	3 TO SOME EXTENT	4 TO A GREAT EXTENT	5 TO A VERY GREAT EXTENT
9.	How adquate for your needs is the amount of information you get about what is going on in other departments?	☐	☐	☐	☐	☐
10.	How adquate for your needs is the amount of information you get about what is going on in other shifts?	☐	☐	☐	☐	☐
11.	How receptive are those above you to your ideas and suggestions?	☐	☐	☐	☐	☐

12. How are the differences and disagreements between units and departments handled in this organization? (Check one)

1. ____ Disagreements are almost always avoided, denied, or suppressed.
2. ____ Disagreements are usually avoided, denied, or suppressed.
3. ____ Sometimes disagreements are acceptable and worked through; sometimes they are avoided or suppressed.
4. ____ Disagreements are usually accepted as necessary and desirable and worked through.
5. ____ Disagreements are almost always accepted as necessary and desirable and worked through.

Exhibit 1-8. Sample portion of a questionnaire used to identify problems that could be overcome through changes in work structure and policies.

How are surveys useful?

For identifying discrepancies between existing designs and human factors criteria.

Survey methods involve reviewing specific design features, taking measurements (e.g., of viewing distances and angles, lighting, noise levels), and comparing results to human factors criteria. A number of checklists have been developed to support human factors surveys in nuclear power plants (e.g., control room design checklists developed by NRC,[3] and EPRI[4]; maintainability checklists developed by EPRI[5]). When features of interface designs deviate from criteria stated in the checklist, the discrepancy is recorded on a form like that shown in Exhibit 1-9.

Some discrepancies can be conveniently corrected at minimal expense (i.e., using human factors guidelines for design enhancements[6]). Managers will want the significance of other discrepancies (e.g., those involving expensive equipment design changes) to be assessed by a multidisciplinary team considering

- any history of associated error;
- potentials for error;
- likelihood of recovery from error; and
- consequence of error, given the worst likely set of circumstances.

HUMAN ENGINEERING DISCREPANCY REPORT

HED # 52 ORIGINATOR M SMITH DATE 5/17/85

HED TITLE: DISPLAY NOT WITHIN RECOMMENDED VIEWING AREA

DATA COLLECTION METHOD (check):

✓ MEASUREMENT/OBSERVATION

✓ QUESTIONNAIRE (record N respondents who identified problem 10)

✓ DOCUMENTATION REVIEW

CRITERION # NUREG-0700 6.1.2.5b(2)

HED TYPE (check): ___ INDIVIDUAL ✓ GENERIC

ITEM TYPE/ EXAMPLES	NOMENCLATURE	PANEL	LOCATION
DISPLAY	IR-4160 TURBINE BEARING TEMP. RECORDER	VB-1	A-5

PROBLEM DESCRIPTION: THIS RECORDER IS NOT WITHIN THE RECOMMENDED ZONE OF 50-65 INCHES ABOVE

Exhibit 1-9. Sample form used in a survey to report design features that don't comply with human factors criteria.

What is task analysis?

A combination of techniques used to describe what personnel have to do so meaningful conclusions can be drawn about how performance can be improved.

There is no single, "best" way to conduct a task analysis because how one is conducted depends on how the information it provides will be used and how important it is to know what personnel have to do. For example, a simple task analysis could involve extracting information from plant procedures about the sequence of personnel interactions with system equipment. But if the procedures are inaccurate, incomplete, or out of date, the value of the description is compromised. Even when augmented by survey and checklist methods, the resulting information lacks many of the descriptive and analytic elements, shown in Exhibit 1-10, that are often needed for predicting performance or systematically improving it.

Better ways to get accurate and comprehensive task information are to confer with experienced operators and technicians, engineers, and work supervisors and to conduct demonstrations of task performance. Experienced personnel may be asked to describe the steps in a task. Or, preferably, they may be asked to "walk through" the task, performing or pretending to perform each step. Personnel may be asked at the same time to "talk through" the task, explaining what they are doing and why. Or, preferably, walk-throughs can be video recorded for later viewing and explanation. When it isn't possible to use actual equipment in a walk-through, effective, economical mockups can be constructed,[6] or training simulators that resemble the actual equipment can be used.

Whichever technique is chosen, qualified engineers are needed to verify that the task steps are necessary and sufficient to satisfy system functional requirements, and supervisors may be needed to clarify information about relevant organizational requirements. Required task behaviors are then described using a constrained list of verbs, as shown in Exhibit 1-11, and an authorized taxonomy of plant system names and alphanumeric codes.

TASK DESCRIPTIVE ELEMENTS	TASK ANALYTIC ELEMENTS
INITIATING CUE	TASK TIME STRESS
INTERFACE LOCATIONS AND ACCESS	TASK COMPLEXITY
ENVIRONMENTAL CONDITIONS	FREQUENCY OF INTERACTIONS WITH SYSTEM EQUIPMENT
LIGHTING	INVOLVEMENT OF OTHER PERSONNEL
TEMPERATURE	TASK CRITICALITY
NOISE	IMPORTANCE OF INTERACTION WITH SYSTEM EQUIPMENT
HAZARDS	LIKELIHOOD OF ERROR
SEQUENCE OF INTERACTIONS WITH SYSTEM EQUIPMENT	EASE OF ERROR RECOVERY
INFORMATION REQUIREMENTS (DISPLAY RANGE, UNITS, PRECISION; COMMUNICATIONS)	CONSEQUENCE OF ERROR
RESPONSE REQUIREMENTS (CONTROL RANGE, UNITS, PRECISION; COMMUNICATIONS)	ENTRY QUALIFICATIONS
SYSTEM EQUIPMENT RESPONSE TIME	ABILITIES
MOVEMENTS (DRIVING, WALKING, REACHING)	APTITUDES
INTERACTIONS WITH DOCUMENTS	ATTITUDES
INTERACTIONS WITH SUPPORT EQUIPMENT	ACHIEVEMENTS
TOOLS AND TEST EQUIPMENT	TRAINING REQUIREMENTS
COMMUNICATION DEVICES	KNOWLEDGE
PROTECTIVE GEAR	SKILLS
TERMINATING CUE	ATTITUDES

Exhibit 1-10. Elements of descriptive and analytic information that can be determined through task analysis.

CLASS OF BEHAVIOR	SPECIFIC BEHAVIOR	
	DESCRIPTOR	DEFINITION
	SENSING	
ATTENDING	Receives	Is given oral, written, or auditory (alarm) signal information.
INFORMATION GATHERING	Observes	Looks at a display.
	Views	Visually scans a display or procedures in a purposeful way.
	Inspects	Studies closely in a critical manner.
	PERCEIVING	
IDENTIFYING OBJECTS, CONDITIONS, AND EVENTS	Locates	After observing, directs attention to a particular object or set of objects.
	Labels	Assigns a name to a condition or event.
	INTERPRETING	
INFORMATION ADAPTING	Tabulates	Compiles a list of values or conditions.
	Interpolates	Estimates an intermediate value between two indicated values.
	Calculates	Mentally performs mathematical computations.
	Translates	Transforms from one expression to another.
DECISION MAKING	Compares	Inspects more than one display, or set of procedures, or matches with information in memory.
	Plans	Considers various courses of action.
	Chooses	Selects after consideration of various choices.
	Verifies	Establishes the accuracy of displayed conditions.
	RESPONDING	
COMMUNICATING	Asks	Poses a question.
	Answers	Acknowledges or responds to a question.
	Directs	States a command for one other person.
	Commands	States a command for more than one person.
	Informs	Makes a statement for general information purposes.
	Discusses	Exchanges information with one or more people.
	Records	Describes in written form.
	Reports	Recounts an action orally.

Exhibit 1-11. Sample portion of a constrained list of verbs for different classes of task behaviors.

What techniques are used to analyze task behaviors?

Depending on the objectives of the analysis, as discussed in other sections of this primer, techniques could include:

- diagraming functional flows between equipment and personnel (see Section 2.1)
- diagramming decision-action paths (see Section 2.1);
- developing a timeline summary of task behaviors (see Section 2.2)
- developing job task lists of the knowledge and skills as well as requisite abilities, aptitudes, and attitudes (see Sections 3.1 and 3.2);
- relating task information requirements and recall demands to what's known about human memory (see Section 3.3)
- diagraming traffic patterns or links between key points on a facility layout drawing (see Section 4.1);
- diagramming operational sequences of crew interactions with system equipment interfaces (see Section 4.2); and
- relating task response requirements to what's known about human physiology and bio-mechanical operations (see Section 4.3).

Computer programs are often used to reduce the labor and help ensure the internal consistency and comprehensiveness of task analysis. But care is advised in selecting computer programs to ensure that the techniques needed for particular applications are supported by the selected program.

Should all tasks be subjected to comprehensive analysis?

No, only those that have significant impacts on plant performance.

It pays to systematically analyze tasks that are critically associated with measures of plant safety, productivity, and availability — particularly tasks that have proven troublesome at the same or similar plants. Historical records and critical incident interviews can be used to identify these tasks.

Selected analyses can be performed on other tasks according to reasonable objectives. For example, if a facility design change is being planned, it's a good idea to diagram traffic patterns and operational sequences of crew behaviors for tasks performed in the specified facility. In contrast, job task analyses performed for the purpose of better stating entry qualifications and training needs should be relatively comprehensive. This helps ensure that basic ability requirements aren't overlooked or needlessly stated and that final skills practice drills can be made to realistically replicate actual conditions of task performance.

How are test and evaluation trials useful?

For evaluating document and interface designs before they're implemented.

Test trials can be conducted using actual equipment, drawings, mock-ups, or a simulator to verify that a design change will have the desired impact on personnel performance. Procedures for conducting test trials usually include:

- creating a representation (e.g., drawings, mock-ups, or simulations) of the planned solution,
- asking personnel to act out relevant task steps using the representation; and
- collecting subjective as well as objective valuative data.

Subjective reactions like how people feel about a solution can be used to indicate the degree of user-acceptance the planned solution will receive if implemented. Objective data like response time and measures of accuracy indicate the extent to which the new design will facilitate required performance.

What benefits have been realized through human factors engineering?

Improved plant safety and substantial savings through increased plant productivity and availability.

In responding to regulatory actions and pursuing self-motivated incentives as well, utility managers have gained some appreciation of the benefits of human factors engineering. That is, some managers helped determine their utility's response to NRC requirements bearing on the mandated industry-wide review and improvement of control room designs. Others have had a hand in implementing performance based training in one or more plants or been concerned with revision of emergency operating procedures or other human factors improvements. At recent meetings and seminars, industry representatives have spoken of the kinds of benefits listed in Exhibit 1-12.

But human factors applications in nuclear power plants have been relatively recent and too sporadic to produce volumes of compelling "before and after" data. Benefits that the utilities are starting to realize can only be suggested by limited operating experience and anecdotal evidence, such as that provided in the following examples.

After redesigning control panels for two units, using redesign recommendations derived from human factors analyses, one utility expects savings of about $728,000 in lost revenues over five years. Operators in these units have greater confidence, which also helps relax some of the public's concerns.[7]

Since going on line, another plant had experienced eight unscheduled shutdowns due to failures of the reactor coolant pump seal. An EPRI study determined that job performance aids covering selected seal maintenance tasks could result in saving of about half the total cost of these shutdowns — or about $42,000,000.[8]

Another example involves human factors evaluation of cooling garments to be worn in the containment building under radiation protective clothing. Protective clothing impairs air circulation and sweat evaporation, causing accumulation of body heat. So heat stress rather than radiation exposure becomes the governing factor for technician stay time. To help improve maintenance productivity, EPRI sponsored tests demonstrating increases in

- technician safety and comfort (i.e., lower heart rate and body temperature, greater ease of movement) and
- efficient work time (i.e., doubled)

through use of a frozen water vest.[9] Different utilities estimate resultant savings of from $33,000 to over $1.2

INCREASES IN	REDUCTIONS IN
SAFETY • PRODUCTIVITY • AVAILABILITY	NEEDLESS COSTS
Reliability and efficiency of personnel performance Adequacy of communications Cost-effectiveness of training Job satisfaction of personnel • Motivation • Confidence • Commitment to achieving plant goals	Occurrence of human error Consequences of error • Number and severity of injuries • Damage to equipment Wasted time and motion Number and qualifications of personnel required Training requirements and attrition Job dissatisfaction of personnel • Turnover • Absenteeism

Exhibit 1-12. Benefits of human factors engineering.

million yearly (the higher figure being from a utility that would otherwise shut down the plant for containment repairs).

In related applications, several plants have used heat stress management guidelines developed by EPRI to govern work in both radioactive and nonradioactive hot environments. Results have shown a significant increase in work performance and plant availability.

Utilities and Architect/Engineering firms are using body dimension information for nuclear power plant personnel developed by EPRI. Such applications have produced increased ease of access for technicians and enhanced control room operator effectiveness.

At least two utilities have completely redone plant labeling to comply with human factors criteria. Personnel report significant increases in readability, legibility, and useability.

In summary, as stated by an NRC spokesperson: "not only are utility personnel coming to realize that the application of human factors principles and techniques is important in ensuring public health and safety, but that these principles can also increase plant availability and save money." [10]

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Section 1.3
Misconceptions

Questions addressed in this section are:

Is human factors engineering more than using common sense?

Why does human factors engineering address apparent trifles, like the separation between a doorknob and the jam?

Isn't human factors mainly concerned about how people interact with knobs and dials?

Can you look up anything you need to know about human factors engineering in a handbook or guide?

Can human factors engineering provide answers to almost any question affecting personnel performance?

Is human factors engineering more than using common sense?

Much more.

Everyone likes to see evidence of what's called common sense. But sound designs and programs are easier to recognize than arrive at, and not all that commonplace in a complex society. You don't have to look long and hard for examples of everyday nonsense: things that don't work the way you'd expect, or information that confuses more than it enlightens.

What makes sense obviously depends on a person's perspective (as a user, or designer; or as a message receiver, or sender). It also depends on the knowledge base that people have in common. For example, engineers laying out the touch telephone pushbuttons believed the zero should be placed before one on the keypad. But, most people think of zero as coming after nine. Research showed that many costly dialing errors could be avoided by placing the zero after the nine on the keypad.

Anyone can relate some human factors principles to personal experience. If one squares with the other, that's all to the good. But simply being human doesn't make any sensible person knowledgeable about human factors. "I know all about human performance — I'm human" is like the tribal chief's self-defeating reasoning: "My people don't need missionary doctors. They know all about leprosy — they've got it.

Here's a point that might be made with anyone who persists in equating human factors applications with common sense. Say, "We're going to give the technicians working on that noisy turbine deck earplugs so they can hear each other better." You may have to repeat the remark because some people don't equate the wearing of earplugs with hearing improvements.

Whether it makes sense to your listeners will depend on what they know about sound frequencies, hearing and voice ranges, and masking effects. (That is, earplugs block reception of high-frequency noise better than relatively low-frequency speech sounds. So they reduce high-frequency masking effects and actually enable the wearer to better hear speech in a noisy place.[1])

Unfortunately, some managers think it's enough to simply raise the awareness of plant personnel about human factors concerns and then rely on common sense to solve problems related to such concerns. But, research findings about human performance are sometimes unexpected, and principles that are derived from research aren't necessarily consistent with everyones' general experience.

Why does human factors engineering address apparent trifles, like the separation between a doorknob and the jam?

Because performance demands and stresses in the work situation have a combined effect.

The more needless demands and annoyances people have to cope with, the less attention they have left to apply to the task at hand and the greater the likelihood a serious performance error will occur. People can adapt to many nonsupportive factors in a performance situation, but the less they have to, the better.

Human factors applications build in a margin for error by reducing minor as well as major sources of stress. This also helps convey the message that management cares about the safety, comfort, and ease with which people can do their jobs. In short, to resurrect an old saying, "Trifles make excellence, but excellence is no trifle".

Isn't human factors mainly concerned about how people interact with knobs and dials?

No, the era of knobology charecterized by large electro-mechanical controls and limited display designs is coming to an end.

In the past, a lot of human factors research cused on how electro-mechanical instrument design features (e.g., size, shape, and movement characteristics) affect human performance. These findings have long since been translated into specific design criteria, as indicated in Exhibit 1-13, that have become widely known and accepted.

In recent years, human factors research addresses how people interact with more versatile electronic devices and the specific mental, or cognitive, operations reliable human performance depends on. The point is that the human factors knowledge base keeps pace with other technologies that influence ystem design and operations. Human factors engineering doesn't stop with better knobs and dials any more than mechanical engineering stopped with the wheel. Yet the more the focus of human factors engineering seems to expand and change, the more it remains on one thing: improving human performance.

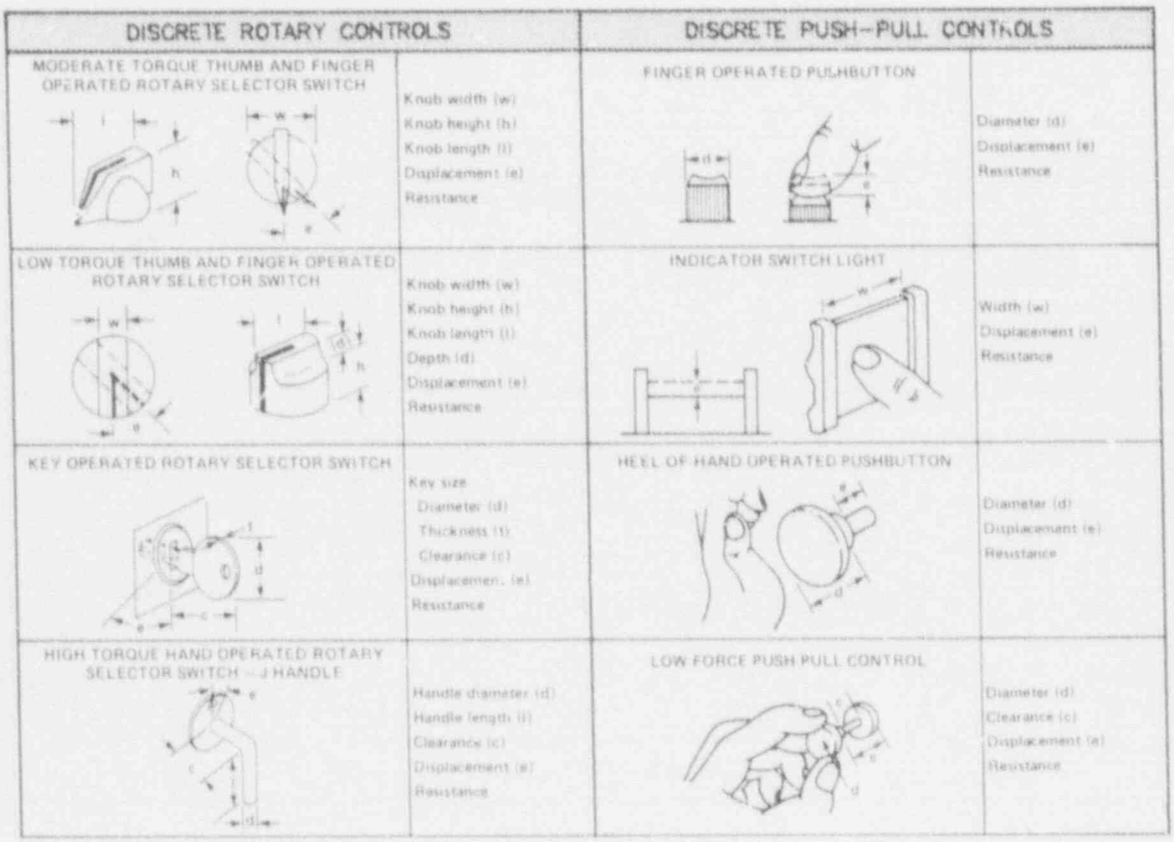

Exhibit 1-13. Human factors criteria include values for all the dimensions of control instruments shown, as well as the minimum separation required between instruments.

Can you look up anything you need to know about human factors engineering in a handbook or guide?

No, the most important information comes from multidisciplinary teams working to solve specific problems.

Human factors handbooks and guides typically emphasize detail, furnishing guidelines or specific criteria for various applications. For example, an EPRI guide addressing control room development provides detailed step-by-step design guidance and criteria checklists, as shown in Exhibit 1-14.[2] But its guidance is generic and doesn't address the features of a particular control room or specific constraints managers have to consider in authorizing design changes. No handbook or guide can eliminate the need to collect situation specific data or substitute for systematic analysis to produce the best solution to a particular challenge.

CHECKPOINT CATEGORY, INQUIRY, AND PAGE REFERENCE	YES	NO	COMMENT NO.
Has the feasibility of providing strategically located repeater stations to enable effective use of radio links been assessed, including attention to avoiding creation of electromagnetic interference with the operation of sensing elements? (pg. 278)			
If repeater stations will be provided, has the feasibility of implementing extensive use of individual pocket beepers been assessed, including the following concerns:			
• Would each beeper incorporate vibra-tactile stimulation for detection and have its own radio pulse code?			
• Have beepers that also include a capability of displaying the telephone number of the calling party been considered? (pg. 278)			
Have capabilities represented by different types of equipment been integrated into an overall communications system plan? (pg. 278)			
Have needs been considered for backup equipment, alternate routes, and load switching capabilities that could be used in case of equipment failure? (pg. 278)			
Has an inventory been prepared, listing the quantities of equipment necessary to support the communications system? (pg. 278)			
Has a communications configuration map been prepared, depicting candidate equipment at each node location? (pg. 278, 279)			
SPECIFIC PRESCRIPTIONS			
Establish Standards for Transmission Characteristics			
Have desirable objectives, or targets been recommended for dynamic range, frequency response (i.e., bandwidth and attenuation distortion) phase shift, and signal loss characteristics of communications equipment transmission? (pg. 279-280)			
Has a dynamic range target of 50 dB been recommended, but has a minimum of about 30-40dB been established? (pg. 281)			

Exhibit 1-14. Sample checklist page on communications system design from a human factors guide.

Can human factors engineering provide answers to almost any question affecting personnel performance?

Easy answers, no; helpful recommendations, yes.

Often the kind of information managers need to make sound, defensible decisions can only be produced by analyzing the tasks affected, interviewing personnel, and implementing trial changes for evaluation in a specific context. Resulting human factors recommendations, identifying and quantifying salient tradeoffs, help reduce the uncertainties managers confront in decision making. Human factors engineering isn't a panacea, but it provides information that can make the differences you're looking for in plant performance.

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Chapter 2
TASK REQUIREMENTS:
Decisions about Personnel Functions, Work Structure, and Policies

This chapter includes three sections that suggest how changes in task requirements — what people are expected to do — can help bring about improvements in plant performance. Section 2.1 suggests how management can change task requirements by reallocating plant functions between personnel and equipment. Section 2.2 indicates how decisions to restructure work — by reorganizing relationships among job positions and reassigning tasks to jobs — can help. Section 2.3 addresses decisions about policies that govern how work is managed, scheduled, and rewarded.

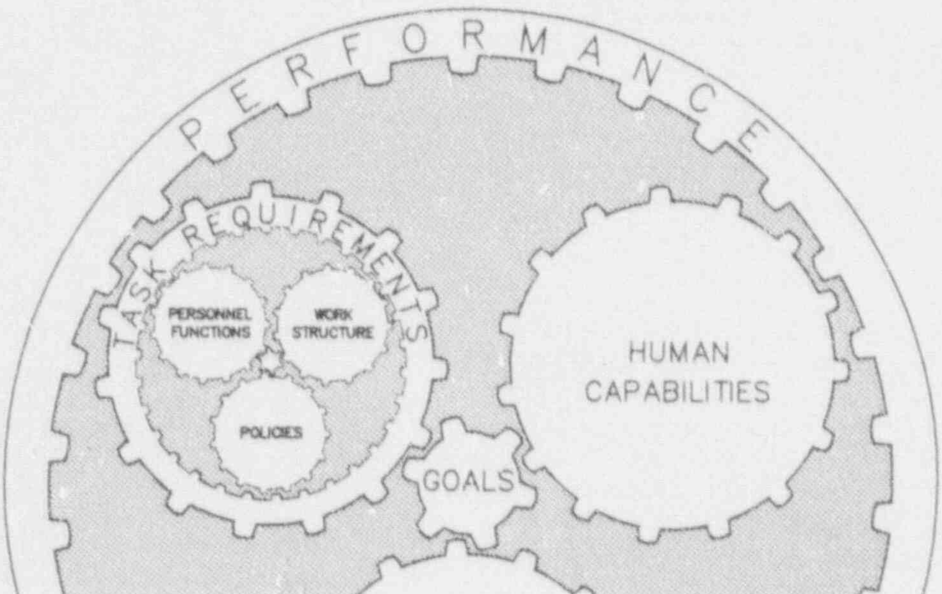

Exhibit 2-1. Task requirements reflect decisions about how functions are allocated between personnel and equipment as well as how work is structured and managed.

Section 2.1

Decisions about Personnel Functions

Questions addressed in this section are:

What progressive decisions can managers make about personnel functions?

What might prompt managers to consider reallocating functions between personnel and equipment?

What information do managers need in reexamining personnel functions?

Are there any pitfalls associated with function reallocation decisions?

How can human factors engineering help managers make sound decisions about function reallocation?

What progressive decisions can managers make about personnel functions?

Decisions that help achieve more effective use of the differing capabilities of people and equipment.

When your plant was being developed, early decisions dictated much about the functions that personnel perform today. That is, functions that equipment couldn't perform well or within cost constraints were allocated to personnel. Since that time, operating experience along with technological advances have provided a basis for reexamining decisions about personnel functions.

Function reallocation is seldom a simple question of reassigning a broad personnel function to equipment. Instead, personnel functions usually have to be broken down to identify specific operations that could be better performed by equipment. But, rather than swinging from reliance on personnel to full automation, the decision is more likely to focus on the tradeoffs of achieving an effective balance between the capabilities of personnel and equipment, as shown in Exhibit 2-2. Sound decisions take advantage of the strengths of differing components and compensate for their weaknesses, increasing performance reliability and often reducing operating costs as well.

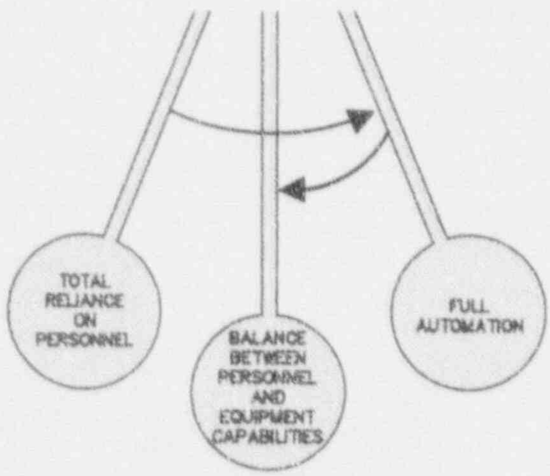

Exhibit 2-2. Rather than total reliance on personnel or full automation, the objective of function reallocation is to achieve effective balance between personnel and equipment capabilities.

What might prompt managers to consider reallocating functions between personnel and equipment?

The impetus for change might include:

- regulatory actions,
- technological advances,
- internal investigations of safety related events, and/or
- specific goals to improve personnel safety.

Regulatory agency actions, such as the NRC requirement to provide a Safety Parameter Display System (SPDS), might prompt a manager to reexamine how functions are allocated. In some plants, for example, the SPDS has been designed to perform some information processing functions formerly allocated to personnel. That is, the SPDS not only indicates safety status as required, but also classifies deviant plant parameters into predetermined categories. Thus, it provides procedural guidance to operators when selected parameters fall outside acceptable limits.

Technological advances, such as the ever increasing capability of low cost computers, are spurring managers to explore a variety of function reallocation opportunities. Computer-based advances run a gamut from sensor data integration and decision making support to maintenance planning and diagnostic aiding.

As participants in INPO's Significant Event Evaluation and Information Network (SEE-IN), many utilities are routinely investigating safety-related events to unearth and report the root causes. Managers can use root cause reports to identify opportunities for reallocating functions to achieve more reliable plant performance. For example, some technician errors in surveillance testing of automatic safety systems might be avoided in the future by use of performance monitoring devices.

Specific goals to improve personnel safety, such as programmatic efforts to keep radiation exposure as low as reasonably achievable (ALARA), may also inspire managers to consider reallocating functions between personnel and equipment. For example, some utilities are exploring the use of telerobotic devices that can be operated by technicians at locations remote from those where hazardous conditions exist.

What information do managers need in reexamining personnel functions?

A description of the functions affected by a potential change, along with information about the feasibility and cost-effectiveness of function reallocation alternatives.

A functional flow block diagram is a useful way of describing the specific functions needed to accomplish a broad function. For example, the function of controlling steam generator level, given a tube rupture, might be described as shown in Exhibit 2-3.

The approach used to describe specific functions should facilitate comparative assessment of the capabilities of both personnel and equipment. For example, detect, match, select, actuate, and verify functions can be related to the capabilities of people or equipment, as indicated in Exhibit 2-4.

The feasibility of having equipment perform variable functions is partially dictated by the extent to which deterministic operations can be defined. Deterministic

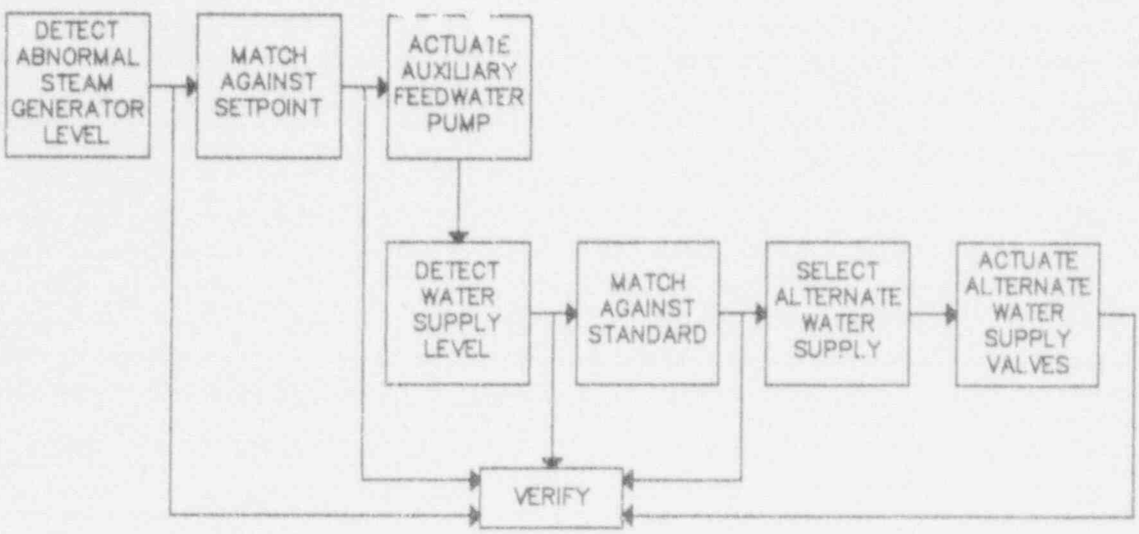

Exhibit 2-3. Sample functional flow block diagram showing the functions needed to control steam generator level, given a tube rupture.

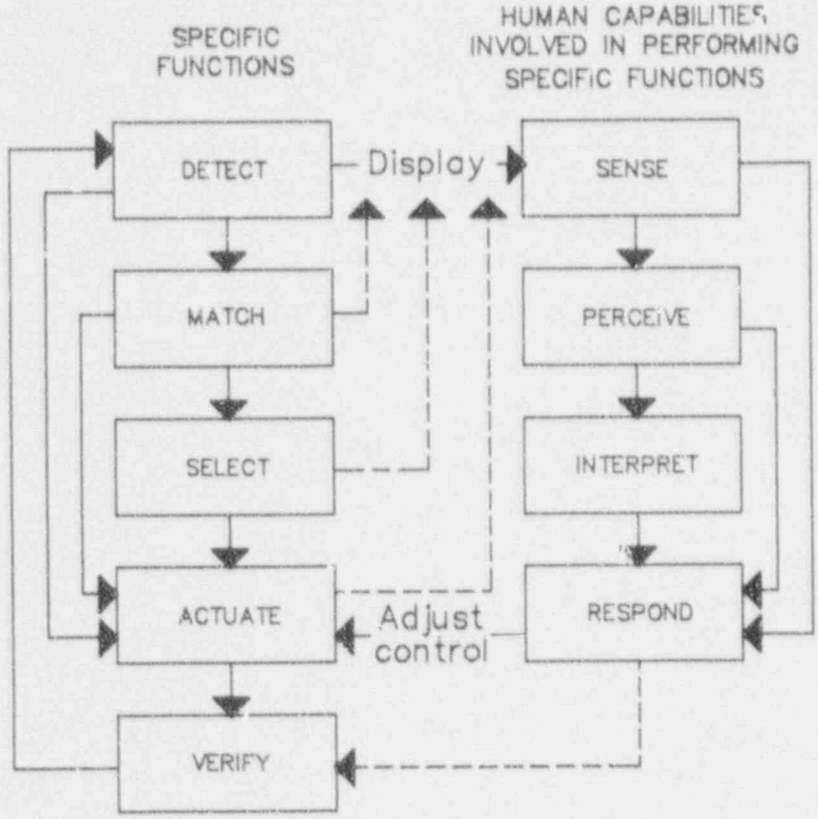

Exhibit 2-4. Relation between specific functions and human capabilities that may be involved in performing them.

operations can be derived from physical laws expressed in mathematical formulae, from a set of rules expressed in the form of algorithms, or from a set of heuristic procedures expressed in the form of sequential steps. If deterministic operations can't be specified, variable functions have to be performed by personnel.

The cost-effectiveness of function reallocation alternatives can be assessed on the basis of identified tradeoffs and priorities. Function reallocation decisions can reduce the number of personnel; required qualifications and training; and the occurrence of accidents and injuries, safety related events, or needless downtime. But function reallocation decisions also affect capital expenditures. Investments in engineering developments may involve some risk. Explicitly stated strategies concerning tradeoffs and priorities among operating costs, revenues, capital expenditures, and development costs provide a basis for assessing function reallocation alternatives.

Are there any pitfalls associated with function reallocation decisions?

Several, their common source being lack of explicit awareness on the part of management that acquiring a new equipment capability represents a function reallocation decision.

Sometimes managers focus attention on equipment changes without recognizing how these changes could impact on human. For example, when many personnel functions are reallocated to equipment, personnel may be left without enough meaningful work during normal operations, and boredom can degrade their capabilities not only to perform routine tasks but to respond to unusual events. Unless they are given adequate practice on tasks required for abnormal conditions, personnel may also be unable to intervene when equipment fails. And experienced personnel may resist learning how to take advantage of new equipment capabilities.

Ways of avoiding these pitfalls include, for example, designing equipment with "embedded training" features to provide stimulation as well as practice opportunities during normal operations. Another is involving experienced personnel in design decisions and making changes gradually to help personnel adapt to them.

How can human factors engineering help managers make sound decisions about function reallocation?

By helping to identify troublesome tasks that are amenable to partial reallocation, by providing specific information about human capabilities and limitations, and by alerting management to interrelated human factors concerns associated with function reallocation alternatives.

Extensive lists are available comparing human and machine capabilities, as suggested briefly in Exhibit 2-5. Updated often because of rapid advances in equipment technology, these lists provide general guidance,[1,2] which usually has to be augmented by specific data.[3,4]

Managers most need to be advised when function reallocation decisions have pervasive human factors implications. The expected addition of a large number of advanced displays in the control room is a good example of function reallocation calling for many interrelated changes. That is, a decision to unburden personnel of some requirements to integrate information may have to be attended by changes in how work is structured and what training is needed as well as in interface designs (as discussed in Chapter 4).

FUNCTIONS	EQUIPMENT STRENGTHS	HUMAN STRENGTHS
DETECT	Senses energies and energy ranges that humans do not, and continuously monitors inputs for slight deviations.	Recognizes patterns and can sometimes discriminate signals embedded in noise.
MATCH	Compares large amounts of data with precise, fixed values.	Can use experience and judgment to anticipate deviations.
SELECT	Selects actions on the basis of predetermined logic.	Can improvise and adopt flexible approaches when solving unique problems.
ACTUATE	Exerts large amounts of force smoothly, continuously, and precisely to track input signals.	Can alter actions based on assessment of plant conditions.
VERIFY	Calculates statistical measures or translates related measures to verify actions have taken place.	Can infer actions have occurred from information about downstream equipments.

Exhibit 2-5. Comparative strengths of equipment and humans for performing specific functions.

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Section 2.2
Decisions about Work Structure

Questions addressed in this section are:

What progressive decisions can managers make about the work structure in a plant?

What might prompt managers to consider restructuring work?

Is there a single, best organizational design?

What human factors methods are useful in redesigning jobs and their interrelationships?

What general principles apply to restructuring work?

What aspects of the work structure can contribute to the job satisfaction of personnel?

What are job performance standards, and why is it important to explicitly define them?

How can human factors engineering help managers make sound decisions about work structure?

What progressive decisions can managers make about the work structure in a plant?

Decisions that achieve an equitable distribution of duties among personnel, enabling all task requirements to be efficiently and reliably met and promoting job satisfaction.

Management decisions about the structure of work determine:

- how comprehensively task requirements are represented in the duties assigned to different job positions
- what tasks are assigned to single job positions (and, in turn, what capabilities different personnel must have to perform job tasks); and
- whether personnel have authority commensurate with assigned duties, receive all the information they need to perform job tasks, and know what's expected of them.

Restructuring work usually entails identifying task requirements that aren't being adequately met and determining how duties could be better distributed either across several jobs or a whole organization. Objectives include increasing efficiency, reducing costs, creating motivating career paths for personnel, reducing the stress or monotony of work, and otherwise decreasing the likelihood of unreliable performance.

When your plant was being developed, job positions and staffing needs were defined according to management assumptions about:

- the equipment related functions personnel would perform;
- needs for planning, supervising, reporting, and coordinating work; and
- the advantages of a particular organizational structure.

Since that time, regulatory actions have imposed additional job tasks and staffing requirements, as have other changes management has initiated.

Different work structures have evolved among the 85 nuclear power units in the U.S. For example, some utilities combine senior reactor operator and shift technical advisor (STA) positions, while others define continuing full-time duties for the STA, and still others treat the STA as an off-site resource available "on call". Marked differences exist not only in the work structure of units with similar facility and equipment designs, but in their performance as well.[1] Those work structures that produce superior performance are more compatible with the requirements personnel have to satisfy. Improvements in plant performance can be achieved by reorganizing job relationships and redefining the duties of some job positions so system and organizational requirements can more easily be satisfied.

What might prompt managers to consider restructuring work?

Changes might be suggested by, for example:

- technological advances;
- investigations of safety related events; and
- goals to increase maintenance productivity.

Incorporating technological innovations (e.g., an advanced display system) call for changes in job design and communications channels across the organization. For example, the operator stationed at an advanced display console might be assigned duties for monitoring plant status and directing control actions that are executed by other operators. In addition, if the same advanced display capabilities provided in the control room are provided in the emergency operating facility and the technical support center, operator responsibilities for communicating plant status information could be greatly reduced.

Investigations of safety related events may prompt other changes in work structure. In one plant, for example, failure to isolate a steam train during maintenance led management to redefine operator duties. Before the event, maintenance support duties could be assumed by any control room operator who acknowledged a request on the paging system (which was used an average of once every 30 seconds during the day.) After the event, management reassigned the duty of supporting maintenance tasks to one operator.

Significant reductions in operating costs can be obtained by establishing maintenance productivity goals and making changes to how work is structured so the goals can be met. In one plant, for example, a study revealed that only about 27% of technician time was typically spent performing equipment related tasks. The rest was spent obtaining work orders and tools, locating equipment, and interacting with security, quality control, and health physics personnel.

Increases in maintenance productivity could be obtained in some plants by reducing the highly specialized nature of some technician jobs. That is, a decision to provide specialty cross-training and broaden the assignment of job duties can reduce wasted time when work would otherwise require several highly specialized technicians, alternatively working and waiting, to complete it.

Is there a single, best organizational design?

None known, but some evidence suggests that highly centralized organizations don't perform as well as decentralized ones.[2]

Centralized organizations, with many vertical tiers, increase the requirement for personnel in management positions to possess broad capabilities. These organizations also rely heavily on effective top-down and bottom-up communications. Decentralized organizations, with fewer vertical tiers and more horizontal branches, reduce capability and communications demands imposed on upper management personnel, but increase the requirements for coordination across groups.

Management span of control and work group size are interrelated concerns in structuring work across an organization. That is, small work groups, from 5 to 10 personnel, not only permit effective supervision, but promote group identification and mutual supportiveness. Evidence is impressively consistent that absenteeism and, to a lesser extent, turnover rises with the size of the work group,[3] and job satisfaction tends to decline with increasing work group size.

Which human factors methods are useful in redesigning jobs and their interrelationships?

Job design methods

Questionnaires or interviews and various task analysis techniques.

Questionnaires and interviews are useful in identifying problems associated with the existing work structure. For example, personnel may indicate that interdepartmental communications are inadequate for supporting performance of their tasks. However, such methods are not particularly useful when attempting to solve identified problems. Task analysis methods can provide the information needed to solve identified problems. For example, such methods provide information that can be used to cluster related tasks into jobs.

Information about the sequence, frequency, and importance of equipment interactions and required communications is useful in assessing workloads and determining where redundant or special supervisory duties should be assigned. Task analysis information can be used to create a timeline, as shown in Exhibit 2-6, providing a basis for better distributing duties across job positions.

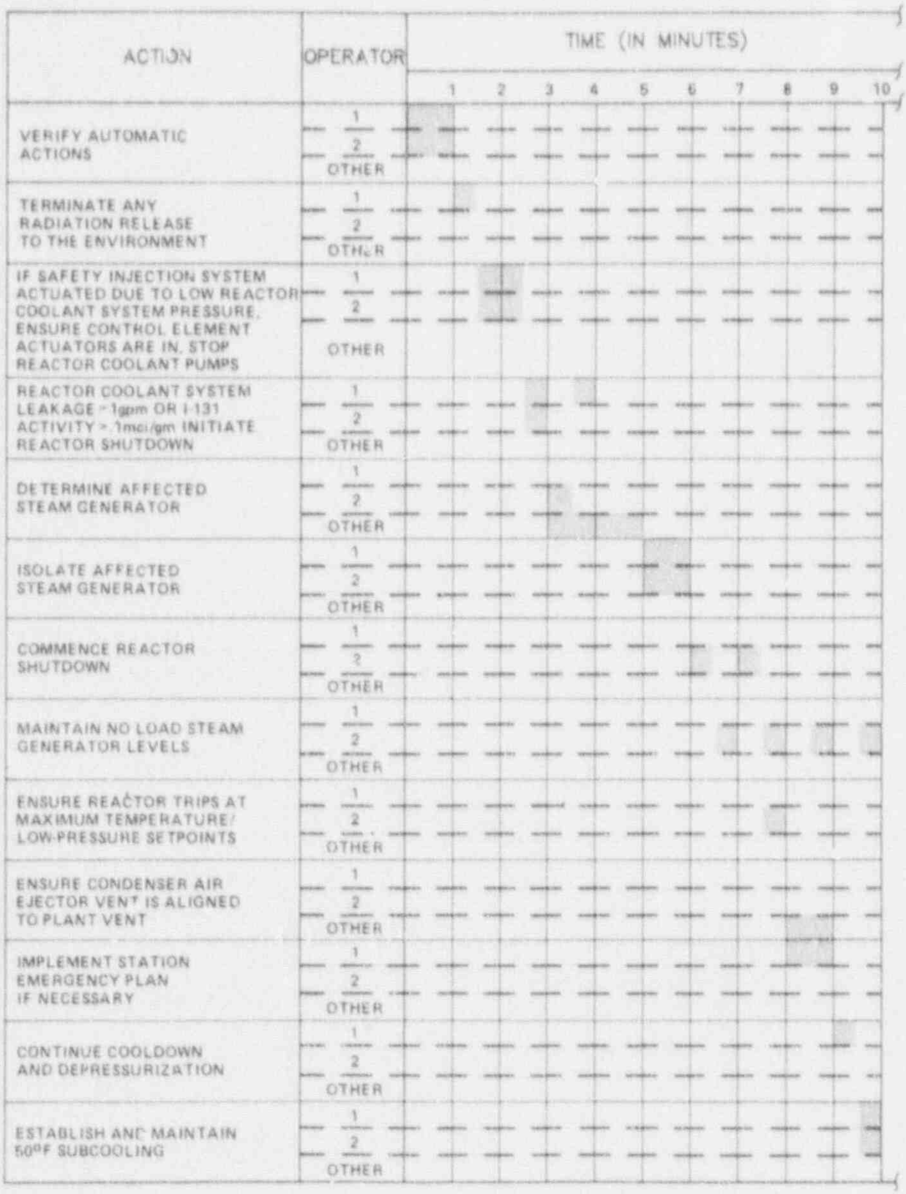

Exhibit 2-6. Sample portion of a timeline summary for a postulated event (i.e., steam generator tube rupture).

Another technique useful in assessing and improving the efficiency of organizational interactions is to develop a sociogram, as shown in Exhibit 2-7. Each department or organizational unit involved in performance of a series of tasks is identified by points on a circle, and lines are drawn to depict the frequency of interactions between units. The resulting diagram summarizes the volume of communications between units and may indicate the need to combine or reassign some duties to facilitate efficient, productive communication performance. In the example shown, for instance, maintenance and engineering indirectly receive information about plant conditions rather than exchanging information with the control room.

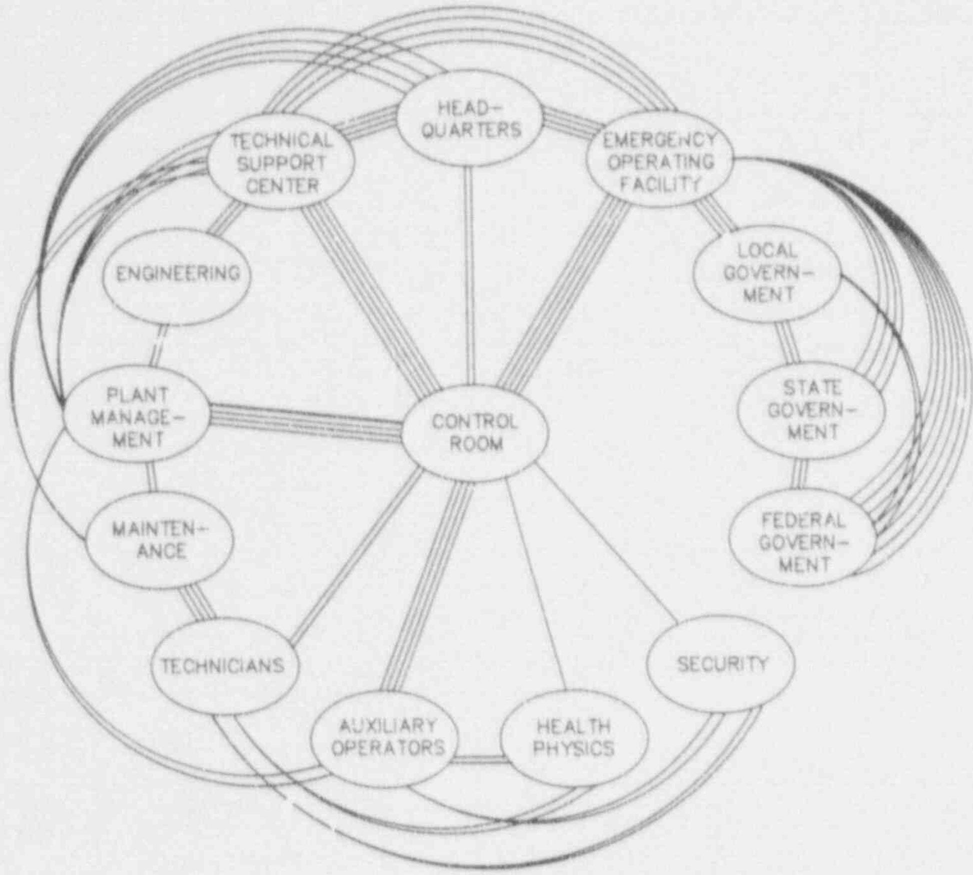

Exhibit 2-7. Sample of a sociogram depicting hypothetical interactions throughout an organization during a safety related event.

What general principles apply to restructuring work?

Principles that offer guidance for reducing selection and training requirements while promoting the motivation and retention of capable personnel, as summarized in Exhibit 2-8.

When possible, whole tasks should be assigned to one job position to produce a sense of responsibility for and achievement in task completion. Redundant assignments (to peers or supervisory personnel) are important to verify correct completion of critical task steps.

Assigning clusters of tasks with related knowledge and skill requirements to single positions helps to achieve economies in training. Similarly, considering the location of required performance in assigning tasks to jobs reduces needless travel and delays in performance. In addition, a special human factors concern is creating job ladders, where the primary difference in a series of positions is in salary and status according to the level of proficiency needed to satisfy task requirements. Job ladders establish a recognized basis for career advancement, an important motivational factor in personnel performance.

Workloads that result from applying these and other principles should then be assessed to determine whether:

- personnel will be occupied and adequately stimulated during typical work periods; or
- time stress could seriously degrade performance in worst case scenarios.

ASPECT OF JOB	DESIGN JOBS SO TASKS:
FUNCTION RELATIONSHIPS	address related functions
EQUIPMENT RELATIONSHIPS	concern similar equipment systems or subsystems,
LOCATION RELATIONSHIPS	are performed in the same general location,
KNOWLEDGE RELATIONSHIPS	demand the same or similar knowledge base,
APTITUDE RELATIONSHIPS	require the same or related aptitudes,
TIME UTILIZATION	will keep the person adequately busy at varied rather than excessively repetitive tasks during a typical work period.
	ORGANIZE JOBS SO:
SUPERVISORY STRUCTURE	there is an explicit definition of responsibility and authority for assigning personnel, distribution and evaluating work and making decisions in emergencies.
CAREER PROGRESSION	each job is related to other jobs where the primary differences in job level is the degree of proficiency.

Exhibit 2-8. General principles that can be applied in restructuring work.[4]

What aspects of work structure can contribute to the job satisfaction of personnel?

The match between the work itself and the capabilities of personnel, the sense of responsibility and achievement each job affords, along with opportunities for growth and advancement.

Experienced managers aren't surprised to learn that salary isn't the major factor in job satisfaction. No amount of salary can compensate for work that personnel perceive as a dull, meaningless, "dead end" way of life. When people believe that are not being adequately compensated for the work they do by salary, status (or perquisites), interpersonal relations, or working conditions, it can lead to job dissatisfaction. But the factors associated with job satisfaction are quite different, as shown in Exhibit 2-9, and are strongly related to decisions about job design.

SATISFACTION	DISSATISFACTION
Work itself	Salary Status
Responsibility	Relations with: Subordinates Peers Supervisor
Achievement	Working conditions
Recognition	Interference with personal life
Growth	Company policy and its administration
Advancement	Quality and quantity of supervision

Exhibit 2-9. Factors associated with job satisfaction are different for those associated with dissatisfaction.

What are job performance standards, and how are they used?

Stated measures of performance where specific values have to be achieved to satisfy functional or organizational requirements, used to evaluate individuals as well as to identify where improvements are needed.

When job performance standards are explicitly defined:

- personnel know what's expected of them and are more likely to bring to management attention anything that interferes with their meeting expectations;
- management can systematically review, evaluate, and provide constructive feedback on personnel performance; and
- measures of actual job performance rather than test results and subjective judgments can be used to evaluate factors in the job situation affecting performance.

Defining reasonable job performance standards requires active participation of work supervisors and the personnel whose performance will be evaluated. Reaching agreement on meaningful job performance standards is often difficult, but it's necessary to avoid the widespread problem of focusing on secondary rather than primary job measures.[5]

Job performance standards can best be derived from an analysis of required system and organizational functions. The purpose of such an analysis is to identify measures reflecting response time and accuracy requirements associated with tasks assigned to single job positions. Quantitative standards that can be objectively defined and measured are preferred over qualitative standards that have to be subjectively interpreted. For example, task and workload analyses could reveal that within a given time (e.g., annually), the utility expects a technician to comply with a given work schedule while successfully performing a reasonable number of preventive maintenance tasks, and completing a number of repairs on certain components (i.e., according to equipment reliability data). This information provides a basis for defining the means by which the technician's performance will be evaluated and rewarded or corrected.

How can human factors engineering help managers make sound decisions about work structure?

By calling attention to problems, providing information about task requirements and workloads, and identifying tradeoffs among structuring alternatives.

The number and qualifications of personnel as well as required investments in training, documents, and interface designs are affected by decisions about work structure. For example, some costs can be reduced by assigning duties to fewer people, but training may have to be increased. And if performance reliability is adversely affected, associated losses may make reductions in staffing a very false economy.

In other cases, investments in interface design or changes in policies may be needed to support decisions about some work structuring alternatives. For example, relocating workshops may go along with redistributing selected tasks to fully achieve increased productivity. And policy decisions, like specifying procedures for performance reviews, may also be needed to reinforce decisions about duties assigned to personnel.

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Section 2.3
Decisions about Policies

Questions addressed in this section are:

What progressive decisions can managers make about plant policies?

What might prompt managers to make policy changes or additions?

Why will information management policies and procedures become more important as applications of digital technology increase?

How do work scheduling policies affect personnel performance and motivation?

Why is it important to provide work breaks during long, monotonous tasks?

How do policies about rewards and discipline influence personnel performance?

How can human factors engineering help managers make sound decisions about policies?

What progressive decisions can managers make about plant policies?

Decisions that foster reliable, productive performance and contribute to the job satisfaction of personnel.

Policies define various aspects of how work is managed, scheduled, and rewarded. Changing policies usually means determining how the psychological, social, and physiological needs of personnel can be satisfied within the context of accomplishing required work. Objectives include increasing productivity, reducing the likelihood of performance errors, and strengthening the motivation of personnel to help achieve plant goals.

When plant policies aren't explicitly defined, various practices simply evolve. For example, if management doesn't set reasonable limits on what amount of overtime it will authorize under what conditions, it may be overpaying for degraded performance that jeopardizes plant goals. Similarly, if management doesn't have a policy to involve personnel in decisions that substantially change plant operations, it not only forgoes having their insights, but may undermine their identification with utility goals and their motivation to help achieve them. Explicitly defined policies are often needed to support decisions about work structure and changes to training, documents, or interface designs.

What might prompt managers to make policy changes or additions?

Reasons including, for example:

- a desire to promote plant programs (e.g, preventive maintenance, heat stress management);
- analysis of unexcused absences during periods of extended downtime; and
- awareness of low morale among personnel and the nature of their complaints.

Many managers try to stay aware of how special programmatic efforts could help them achieve better plant performance. For example, most utilities want to increase their program of preventive maintenance, by using computers to compile equipment history and maintenance information and to produce a more comprehensive preventive maintenance schedule and tracking system.[2] But, policies governing how information will be collected and how decisions will be made are needed to ensure that the program achieves its objectives. Similarly, a number of plants have adopted a heat stress management program that calls for redefinition of specific policies governing work methods in hot environments.[1]

An analysis of absences when excessive amounts of overtime (i.e., more than a 16-hr work day) have been worked may alert managers to the need to change policies governing how work is scheduled. Fatigue degrades performance capabilities, so that personnel who choose to stay home when they're very tired can be doing the plant a favor.

Sometimes existing policies, or the lack of needed ones, result in restricted communication, encourage management insensitivity to personnel needs, or fail to ensure that good performance is rewarded. Problems of morale degrade personnel performance and indicate a need for management to identify the causes, develop solutions, and revise plant policies accordingly.

Why will information management policies and procedures become more important as applications of digital technology increase?

Because the amount of data available will increase dramatically and managing it to produce information is necessary to keep from being swamped with useless data.

Applications of digital technology provide increased opportunities for recording, summarizing, and reporting data resulting from plant operations. But data needs to be converted into information, providing a basis for decisions. For example, equipment operating times may be recorded and the information used for managing a preventive maintenance program. Similarly, recordings of plant measures prior to an event may be used to diagnose faults. Given there's little precedence for having access to such a large amount of data about plant operations, management will have to consider how to reap the full benefits of digital technology applications to obtain useful information without being overwhelmed by meaningless data.

One of the improvements associated with better information management opportunities could be longer-term planning and coordination, which many personnel perceive as contributing to organizational effectiveness. That is, if planning is done as much as 6 months in advance of a work requirement, personnel are more likely to think it effective, as shown in Exhibit 2-10.[3]

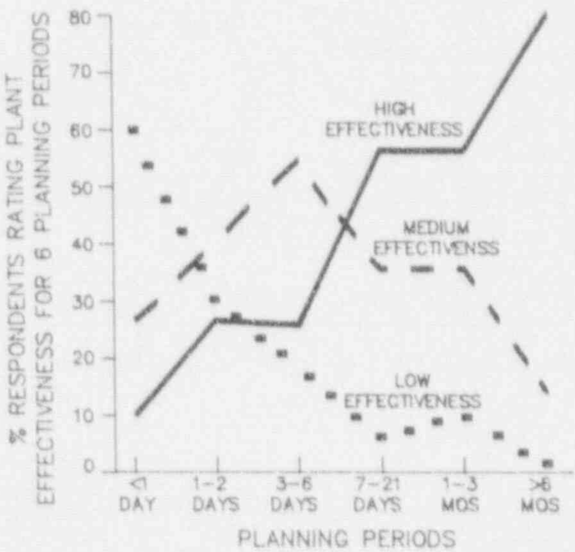

Exhibit 2-10. Relation between how far in advance planning is done and its perceived contribution to plant effectiveness.

How do work scheduling policies affect personnel performance and motivation?

By influencing productivity, safety, and family and social life.

Work scheduling policies determine the amount of overtime (i.e., hours over 8 worked per shift), the duration of shifts, and the type of shift worked (i.e., fixed or rotated). Policies permitting excessive overtime (e.g., more than 600-hrs per year) increase the number of personnel who report productivity and family/social problems, as shown in Exhibit 2-11. The number of people reporting safety problems first increases when more than 200 overtime hours are worked and then declines when overtime in excess of 600 hours is worked. The decline may be due to compensation by personnel who recognize they are fatigued.

Personnel may compensate for fatigue by making a special effort to work carefully, but continual overtime reduces daily productivity by about 25 percent. Other industries have found that about the same amount of work is accomplished in 10 hours as in 8 after people have been working a 10-hr shift for a couple of weeks or more.

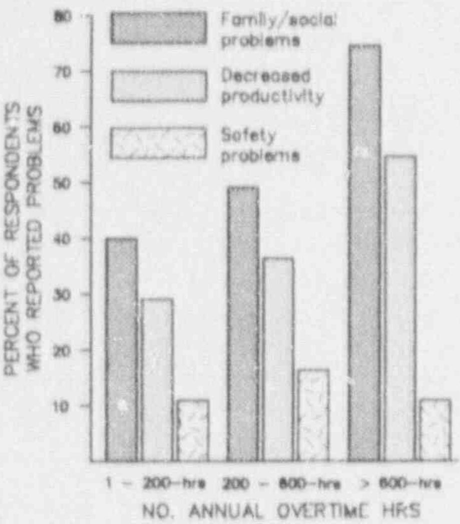

Exhibit 2-11. Relation between annual overtime hours worked and the percentage of personnel who reported family/social problems, decreased productivity, or concern about safe performance.

Rotating shifts cause disruptions in biological rhythms, or cyclical changes in physiological measures that occur over time. Biological rhythms that occur daily or over a 24-hour period are called diurnal and circadian rhythms respectively. Disruptions of such rhythms result in sleep loss and selectively affect certain abilities. For example, th[illegible]ability to retain information in short-term memory [illegible]uced more than some other abilities when biolo[illegible]rhythms are disrupted. Personnel generally shake [illegible]ngs of sleep loss within 2–4 days, depending on the individual. But it's usually necessary for people to work the same schedule for 2–3 weeks (3 weeks preferred) before physiological measures fully adjust to the schedule. Rotations forward in time are easier to adapt to than backward rotations.

Social factors also play an important role in how well people accept different shift rotation schedules. Missing opportunities to spend time with family members, participate in social occasions, and attend amusements offered during week-end and evening hours can cause personnel to feel resentful toward the utility and unmotivated to perform well in their jobs.

Problems associated with rotating shifts can be avoided by establishing fixed shifts. Fixed shifts have the advantage of permitting people to arrange their lives and adapt to working a particular shift. Another advantage is that the same people work together over long periods and develop a team spirit. But, as many managers already know, it's difficult to find people who are both qualified to perform certain jobs and who are willing to consistently work night or graveyard shifts. Where problems associated with rotating shifts can't be avoided, other means have to be used to compensate for performance losses (e.g., changes in interface designs, training, or documentation).

Why is it important to provide work breaks during long, monotonous tasks?

To keep the attention of personnel at an acceptable level throughout each shift.

During periods of time when very little is happening, a person's attention level gradually decreases. In addition, lapses in attention, sometimes referred to as periods of micro-sleep, occur with greater frequency and duration. Toward the end of a work period, attention level picks up and fewer lapses occur.

Scheduled work breaks, where the person is relieved from duties and is free to leave the job situation, partially offset declines in attention. Although attention level may not fully recover to the level at the beginning of work, the expectation of a break and the stimulation obtained during the break slow the continuing decline.

How do policies about rewards and discipline influence personnel performance?

Anticipated rewards continually motivate personnel performance, where discipline produces only temporary improvements.

Effective management emphasizes rewards and deemphasizes penalties. But before management can appropriately reward personnel performance, it has to define job performance standards and also determine what personnel consider most rewarding. Job performance standards should be defined and fully understood by both the performer and the supervisor who assesses performance. Effective rewards are likely to include providing career advancement opportunities and various means of formally recognizing work well done.

How can human factors engineering help managers make sound decisions about policies?

By helping to identify the effects of existing policies on performance and by recommending where new or additional policy statements may be beneficial.

Interviews and questionnaires are useful in assessing the impact of existing policies. For example, the critical incident technique could be used to gather data on absenteeism in your plant. Personnel could be asked to provide an account of unusual events that occurred on the day preceding an absence. Once a sufficient sample of such accounts is obtained, they could be analyzed for commonality and recommendations could be developed to reduce common causes for absenteeism. For instance, if a link is discovered between the physical demands of some maintenance tasks and subsequent technician absence, ways can be explored of reducing the physical demands of the tasks in question.

New policy statements may be needed to implement effective use of job performance standards. Human factors engineering also offers techniques for developing standards that can be used to evaluate personnel performance, providing a basis for appropriate rewards. Additional policy statements may be needed to suppon management decisions about, for example, responsibilities for conducting or participating in interdepartmental meetings, effective implementation of special programs, or assuring safer, more reliable performance of already established task duties.

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Chapter 3
HUMAN CAPABILITIES
Decisions about Personnel Selection, Training, and Documents

This chapter discusses how human capabilities — *what people can and are inclined to do* — relate to task requirements and interface designs. Section 3.1 addresses selecting personnel on the basis of abilities, aptitudes, and attitudes required to successfully complete training and perform job tasks. Section 3.2 indicates how decisions about training determine whether personnel possess all the knowledge, skills, and attitudes their jobs require. Section 3.3 discusses decisions about procedures and other documents that can relieve excessive demands on the capabilities of personnel when they're performing tasks.

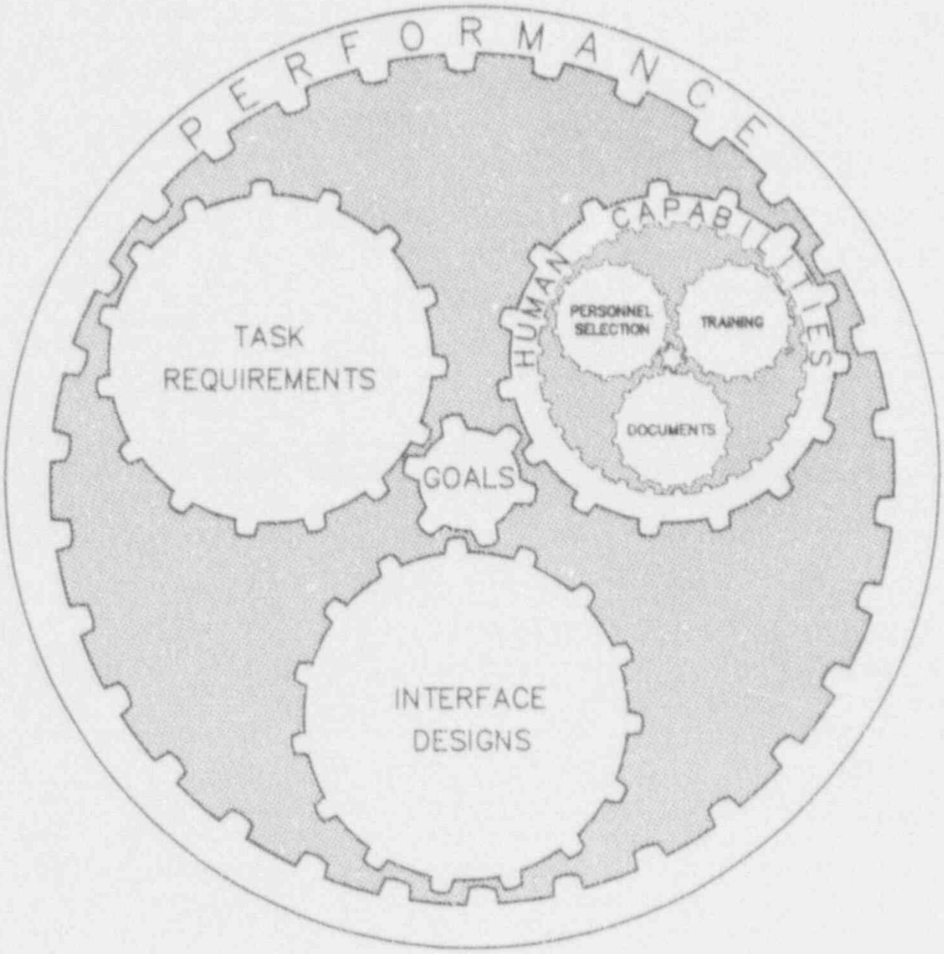

Exhibit 3-1. Information about human capabilities supports decisions about personnel selection and training as well as needs for procedures and other documents.

Section 3.1
Decisions about Personnel Selection

Questions addressed in this section are:

What progressive decisions can managers make about personnel selection?

What might prompt managers to consider changing personnel selection at their plant?

How much information do personnel administrators generally get about job tasks?

What's wrong with basing selection decisions on the concept of what an average person can do?

What information provides a basis for cost-effective selection strategies?

What distinguishes abilities and aptitudes from attitudes and capabilities?

What variety of screening instruments are available to support personnel selection decisions?

What innovations in testing can be applied to achieve effective and economical selection of personnel?

How can human factors engineering help managers improve personnel selection at their plant?

What progressive decisions can managers make about personnel selection?

Decisions that help ensure a better match between the capabilities of personnel and the performance demands of job tasks.

Analyzing specific performance requirements provides a sound basis for defining selection criteria. In a performance based selection program, the abilities, aptitudes, and attitudes associated with training and job success are specified before job opportunities are announced. Appropriate tests and questionnaires can then be administered to objectively assess the qualifications of applicants. These results can be combined with information derived from resumes, references, and interviews to predict which applicant(s) will best meet job performance demands.

In the early days of the nuclear utility industry, seasoned personnel weren't available and training hadn't been fully developed. So selection decisions favored people with some relevant experience in nuclear submarines or fossil fuel plants. Since then, the importance of specific experience has diminished, and utilities have a lot to gain in reconsidering how job applicants are screened. Hiring decisions don't have to be largely subjective and intuitive. Personnel administrators and managers alike can act and make decisions with enough information to justify confidence in the long-term results.

What might prompt managers to consider changing personnel selection at their plant?

The following problems that may be associated with earlier selection methods:

- training costs and attrition;
- rates of turnover, absenteeism, and tardiness; and
- rates of accidents and personal injuries as well as insurance costs.

Deficiencies in personnel selection are reflected in needlessly high costs of training. Attrition is an indicator of this problem. In some plants, for example, management fully expects about half of the people selected for control room operator training to wash out within two years. The costs of this approach can be compared to those of better screening applicants on the basis of aptitudes associated with timely, successful completion of training.

High turnover, absenteeism, and tardiness are other indicators of the need to better screen job applicants. For example, people who have difficulty coping with some task stresses or who will probably find shift work unsatisfactory can be identified before they are hired, trained, and put to work in a job for which they're ill suited. Abilities and attitudes that people bring to work situations are also reflected in accident and injury statistics. For example, the abilities to hear alarm sounds, sense unusual odors, and keep postural balance could be important in some maintenance job positions. Similarly, a predisposition to follow rules and procedures can be an important attitudinal factor in reducing accidents and injuries as well as associated insurance costs.

How much information do personnel administrators generally get about job tasks?

Usually not enough to take advantage of screening instruments that are commercially available.

Personnel administrators are typically given position descriptions that contain general statements about the responsibilities assigned to each job. They may establish rapport with work group supervisors and so discover more about the demands of certain jobs. But information obtained informally lacks the rigor needed to make effective use of job screening instruments.

What's wrong with basing selection decisions on the concept of what an average person can do?

No average person exists.

Measures of any ability are normally distributed among the general population. Plotted out, a normal distribution is bell-shaped, as shown in Exhibit 3-2. The extremes represent people who're far above or below average in a specific ability, while the middle portion represents the normal range.

A person who's within the normal range in one ability or group of related abilities may be exceptional (i.e., above or below the normal range) in others. So it's meaningless to say that "the average person" should be able to perform a certain task. It's not the same as saying that the task requires no exceptional abilities. Even when the latter is true, you want to screen out applicants who don't possesses measures for required abilities that fall within the "normal" range.

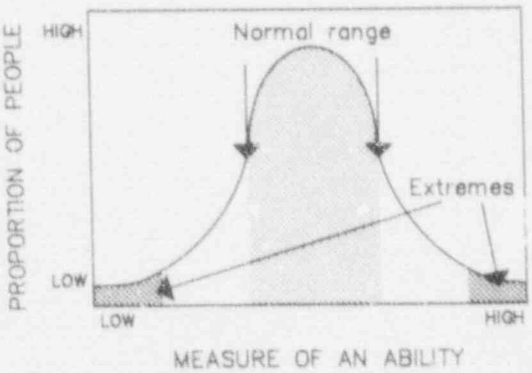

Exhibit 3-2. Plotted, the normal distribution of any ability is bell shaped, with most people in the normal range and far fewer people at either extreme.

What information provides a basis for cost-effective selection strategies?

Information about:

- the labor market;
- the job positions to be filled;
- the knowledge, skills, and attitudes each job requires and what training the utility intends to offer;
- the aptitudes needed to complete training within the alloted time as well as the abilities needed to satisfy performance demands on the job;
- whether needs for unusual capabilities can be reduced through human factors applications; and
- what screening instruments could be effectively applied.

With this information, managers can better appreciate the tradeoffs involved in personnel selection. Estimating the impact on training time and costs of accommodating people who lack relevant aptitudes and achievement levels (e.g., in reading) influences what investment it's appropriate to make in personnel selection. Similarly, knowing what document and interface design changes would be needed to accommodate people who're far outside the normal range on specific capabilities enters into the tradeoffs.

What distinguishes abilities and aptitudes from attitudes and capabilities?

The extent to which they're attributable to experience and can, therefore, be changed.

Characteristics and potentials inherent at birth are a person's basic abilities and aptitudes. They can be developed, but not created where they don't first exist. Attitudes and capabilities, on the other hand, reflect both heredity and experience.

Abilities include:

- sensing (e.g, vision, audition);
- processing (e.g., attention, memory, perception, interpretation), and
- responding (e.g., speech, muscular action).

Aptitudes are innate potentials for developing abilities into capabilities through specific learning experiences. Aptitude levels predict the extent to which — given opportunity — a person will acquire the knowledge, skills, and attitudes needed to perform a job.

Attitudes are related to innate personality variables, but they're also shaped by experience. Long-held attitudes can be very resistant to change. So it's useful to consider job-required attitudes in defining personnel selection criteria. Effective training can then be expected to further shape and reinforce attitudes needed for safe, reliable performance.

Capabilities represent all of a person's achievements, or what the individual has done to develop inborn characteristics. They also reflect expectations and habitual ways of responding that the person has acquired.

What variety of screening instruments are available to support personnel selection decisions?

Ability, aptitude, and achievement tests as well as personality and attitude surveys.

Ability tests provide both psychological and physiological measures of inherent individual differences. They include, for example, tests of hearing, perception, memory, and motor abilities as well as tolerances to environmental conditions like dust, chemicals, and heat. Aptitude tests predict success in scholastic or differing vocational endeavors, while achievement tests assess various knowledge and skills a person already possesses. Personality and attitude surveys provide a format for interpreting responses to questions about personal values, beliefs, and preferences.

The preeminent source of information about psychological tests is the Mental Measurement Yearbook series (with nine editions published in the years 1941 through 1985). The most recent edition contains descriptions and critical reviews of 1,409 instruments produced or revised in the last seven years.[1] As shown in Exhibit 3-3, personality and vocational aptitude tests account for more than 40% of the recent additions.

CLASSIFICATION	NO.	%
Personality	350	24.8
Vocational aptitudes	295	20.9
Languages	134	9.5
Intelligence and scholastic aptitude	100	7.1
Reading	97	6.9
Achievement batteries	68	4.8
Developmental	56	4.0
Mathematics	46	3.3
Speech and hearing	39	2.8
Science	26	1.8
Motor/visual motor	23	1.6
Neuropsychological	14	1.0
Fine arts	9	.6
Multiaptitude	8	.6
Social studies	5	.4

Exhibit 3-3. Major classification of 1,409 tests produced or revised in the last seven years.

You should be aware that if numerous overlapping tests are administered in personnel selection, costs will be needlessly high and managers will have more data than are helpful to support practical decisions. To interpret test scores, managers also need an understanding of the behavior domain each screening instrument is designed to assess and the statistical properties of scores provided (including, e.g., the standard error of measurement). Management also has to be concerned about protecting the rights of applicants.[2] For example, applicants have the right to be informed of how test results will be used before being tested.

What innovations in testing can be applied to achieve effective and economical selection of personnel?

Automated testing.

A number of potential screening instruments have been programmed for personal computers to administer, control, and score tests as well as analyze the results.[3] Compared to traditional paper and pencil methods, automated testing:

- fully standardizes administration, including all instructions, as shown in Exhibit 3-4;
- reduces testing time
- can measure more sensory abilities (e.g., dynamic visual acuity, hearing);
- controls stimulus duration in memory testing;
- can measure response times as well as number and percentage correct; and
- can readily track and summarize results by test taker identification number.

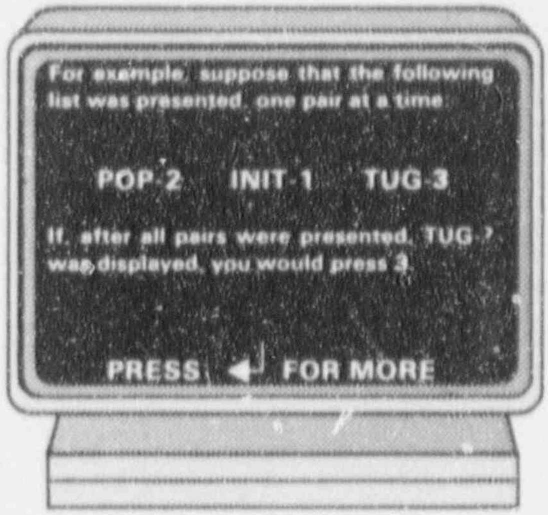

Exhibit 3-4. Automated testing allows fully standardized administration, including all instructions.

In addition to use in personnel selection, automated tests may also provide opportunities for personnel to determine potential performance deficits on the job. Stress, illness, or fatigue, for example, can degrade a person's capabilities to perform job tasks. Immediate results of automated testing can alert a person to avoid error-prone performance that could result in self-injury or damage to equipment.

How can human factors engineering help managers improve personnel selection at their plant?

By analyzing job-required capabilities and training plans to the level required to state selection criteria and by suggesting where beefing up selection isn't the best solution to a performance problem.

To accomplish personnel selection within constraints of the laws on equal employment opportunity, industry is obliged to:

- explicitly establish the connection between job performance requirements and screening instruments;
- use screening instruments that have demonstrated validity; and
- apply the screening instruments equally to all personnel, including those currently employed.

Task analysis establishes the link between job tasks and required capabilities, providing justification for proper use of screening instruments. Task analysis results enable a utility to develop compatible performance-based selection and training strategies, reducing attrition and helping ensure that its personnel are able to satisfy even the unusual demands (e.g., ability to withstand heat stress) of their jobs.

Alternatively, human factors engineering can reduce needs for exceptional abilities and compensate for shortcomings in the capabilities of personnel. Human factors applications in training and documents can facilitate learning and remembering. Interface design recommendations can, for example, reduce needs for superior sight or unusual muscular strength and dexterity. Where human factors engineering can cost-effectively reduce the demands of job tasks, management has to be advised of the implications for personnel selection.

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Section 3.2

Decisions about Training

This section addresses the following questions:

What progressive decisions can managers make about training?

What might prompt managers to consider improvements to training?

What's the relation of human factors engineering to current training technology?

Why is performance based training superior to that developed solely by subject matter experts?

What distinguishes knowledge from skills?

What instructional features account for major differences in development and delivery costs?

What are the comparative advantages of different kinds of training devices?

What's transfer of learning, and why is it important?

What's overlearning, and when is it justified?

How can human factors engineering help managers make sound decisions about training?

What progressive decisions can managers make about training?

Decisions that hold training investment costs in justifiable bounds while helping to ensure that personnel are able to satisfy job task requirements under all operating conditions.

In a performance based approach to training development, training needs are identified by defining differences between the capabilities needed to satisfy job task requirements and the qualifications of selected personnel. These needs are then formally stated as training objectives (addressing the behaviors a person has to demonstrate, under what conditions, and to what standards on the job). Appropriate instructional information (i.e., facts, procedures, rules, and principles) and opportunities to practice can then be provided to establish the capabilities that demonstrate achievement of training objectives.

In the early days, most utilities relied on subject matter experts to develop and deliver training, using vendor-supplied manuals and piping and instrumentation diagrams to support lectures. Licensed operators had some opportunities to practice skills using a generic simulator, but other personnel typically had to develop capabilities as apprentices on the job. More recent years have seen dramatic changes in the training provided throughout the industry. Today, for example:

- an average of five training specialists and twenty-four instructors are at work in each plant;
- expanded classroom and laboratory facilities include sophisticated training materials and devices; and
- full scale simulators of the actual control room are in increasingly wider use.

Within this context of long-term commitment, management needs to be advised about the cost-effectiveness of potential training improvements. Utility managers also want assurance that training will continually be responsive to changes in task requirements and equipment interface designs as well as to performance deficiencies identified on the job.

What might prompt managers to consider improvements to training?

Some leading concerns are, for example:

- anticipated changes in regulatory requirements and INPO accreditation standards;
- investigations of safety related events;
- needs to justify high investments in training; and
- specific goals to improve personnel safety.

Experts within the nuclear power community are forecasting that within the next 7 years, major changes in plant operating requirements will impact on training development.[1] For example, operator qualification and refresher training will probably continue to increase in time alloted and the realism required in skills practice. Other personnel, a variety of technician trades for example, are also likely to receive more training, with objectives including more stringent performance-based criteria. So leaders in the utility industry will want to be prepared for, or get a few jumps ahead of, anticipated regulatory actions.

Despite recent high investments in training development and delivery, deficiencies in training are still often cited as a root cause of safety related events.[2] Root cause reports, performance reviews, and critical incident interviews provide information by which management can identify needs to revise and expand the training currently provided.

Manager's who're concerned about justifying the investments their utility makes in training recognize that capital and operating dollars are two different things. That is, a utility may be willing to make capital investments in training (e.g., acquisition of a $6 million plant-specific simulator), but be unwilling to incur the cost of additional training staff.[3] Cost/benefit analyses of potential training improvements can provide the rationales management needs (e.g., human factors impacts on plant safety, productivity, and availability) to authorize training expenditures that offer best returns.

Specific goals to improve personnel safety may also suggest some improvements to training. For example, personnel can be trained to recognize when they're beginning to suffer heat stress and how to take advantage of countermeasures. Similarly, a simple mock-up can be used to provide technicians with enough practice in performing repair actions to reduce by as much as a third their stay times in hazardous areas of the plant.

What's the relation of human factors engineering to current training technology?

The relation of a forerunner that's helped to establish and elaborate the step-by-step process of developing performance-based training.

Task analytic methods, a cornerstone of human factors engineering, also serve as the foundation for performance-based training. In addition, the techniques applied in defining and sequencing training objectives, presenting instruction, and establishing training device requirements are derived from learning theory and human factors research. Strong bonds between the two disciplines enable each to complement the other in important ways.

Why is performance-based training superior to that developed solely by subject matter experts?

Because the performance-based approach is more objective, thorough, and reliable.

Subject matter experts are what the term implies: individuals who're recognized for their mastery of specific areas of knowledge. But, their mastery may not extend to instructional technology. The opinions and insights of subject matters experts are always valuable in developing training. But, in contrast, the performance-based approach to training development relies on the combined capabilities of a team composed of:

- instructional technologists;
- training specialists;
- media specialists;
- personnel who're experienced in performing job tasks; as well as
- subject matter experts (who understand the physics, chemistry, mechanics, or electronics underlying plant operations).

In addition to drawing on more diverse capabilities, the performance-based approach is a systematic and well-established process, as shown in Exhibit 3-5. It reduces the chances of, for example, overlooking important training needs or failing to provide training features that facilitate achievement of specific objectives.

What distinguishes knowledge from skills?

The ways in which they're acquired.

Knowledge can be acquired when information is provided by using instructional techniques, including:

- lecture and supportive materials;
- workbooks; or
- interactive devices.

In contrast, skills can only be acquired through practice, using:

- actual equipment;
- mock-ups;
- part-task trainers; or
- full scope simulators.

What instructional features account for major differences in development and delivery costs?

Pacing, type and frequency of testing, branching levels, and use of dynamic representations.

Pacing, or the rate of presenting instruction, may be geared to the slower learners in a group (group-paced) or to each individual's learning rate (self-paced). Testing may occur before instruction (pre-test) as well as afterward (post-test) — with varying frequency (e.g., with each block of instruction or only at the end of a

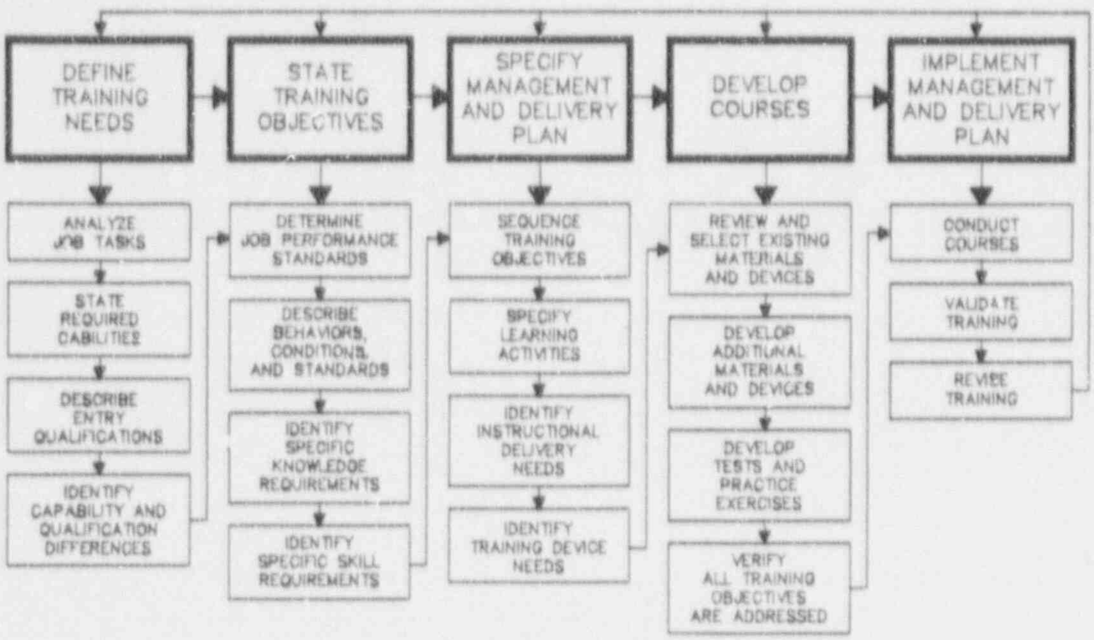

Exhibit 3-5. Variously known as, for example, instructional system design, systems approach to training (SAT), or training system development (TSD), the process of developing performance based training includes these major steps.

course). Branching, or providing instruction at different levels of detail, may be included to accommodate ranges of aptitudes and capabilities among the personnel being trained. Dynamic representations (e.g., animation, film, or video recordings) may also be included to facilitate learning.

Different combinations of features are typically associated with various instructional techniques. For example, lectures are normally group-paced and usually include infrequent testing, little opportunity for branching, and few dynamic representations. In contrast, self-paced workbooks typically provide frequent tests and some branching but no dynamic representations. Interactive computer/video presentations are also self-paced and generally use many pre- and post-tests, along with at least three levels of branching and diverse dynamic representations.

Although arguments have been advanced, it hasn't been demonstrated that one instructional technique consistently results in more effective training than the others. People achieving training objectives with one instructional technique perform as effectively as those who are trained with another. But different combinations of features unquestionably affect the costs of developing and delivering instruction, as shown in Exhibit 3-6.

Combining features like self-pacing, frequent pre- and post-tests, branching, and dynamic representations are sometimes considered to be advanced training technology applications. And, such applications not only reduce instructional delivery time but attrition as well.

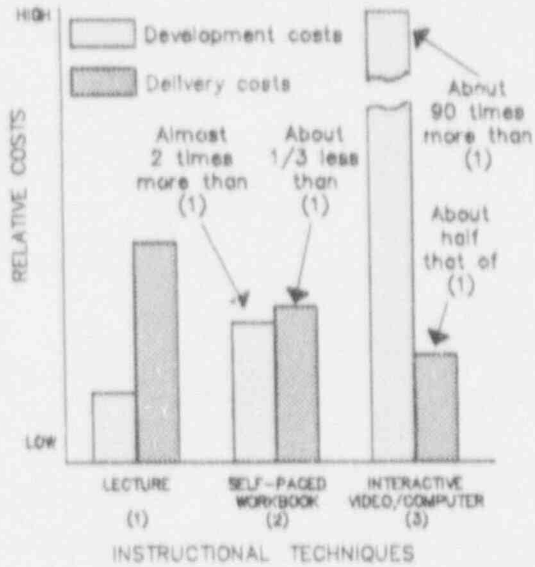

Exhibit 3-6. Relative development and delivery costs for various instructional techniques.

Still, it takes a large number of people who will receive this kind of instruction over the life of the plant to justify the substantially greater development costs.

The point is that instructional features should be selected on the basis of what the utility is trying to accomplish rather than on advanced training technology applications. The type of training being provided (e.g., individual or team), the number who have to be trained, and if the training need is continuing or short-lived should be considered.

What are the comparative advantages of different kinds of training devices?

Some low-cost devices are useful for training selected skills, thereby reducing the time needed to practice using more expensive training devices or being trained on the job.

Skill acquisition occurs in stages. Behavior in early stages is characterized by intense concentration and conscious awareness of each step taken. Extraneous stimuli or distractions easily disrupt the performer's concentration. And, at this stage, feedback about the appropriateness of each action is very important. As training progresses, performance requires less attention. The performer learns to ignore distractions and requires less frequent feedback. Once a skill has been fully acquired, people can execute it almost automatically, with little conscious effort, and evaluate the acceptability of their own performance.

Training devices are useful when actual equipment in on-the-job situations:

- presents risks to personnel or equipment;
- exposes personnel to extraneous stimuli and distractions;
- provides little information about the acceptability of steps taken by personnel; and/or
- doesn't often represent the conditions for which personnel require practice.

In early stages of skill acquisition, mockups are useful for providing procedural skills practice. Modest investments in mockups can have big payoffs when:

- it takes a long time to learn sequences of steps;
- the time to complete the steps is critical; or
- an error in performance could be costly.

Other part-task trainers can effectively provide opportunities to practice selected skills. For example, a trainer designed to provide practice on diagnostic skills included prompting about logical approaches to troubleshooting. Personnel trained with this feature retained diagnostic skills longer than those who were trained without it.[4,5] Similarly, in other applications, important increases in decision making and problem solving skills have been achieved using relatively low cost, part-task trainers.[6]

Use of a costly full-scope simulator should be reserved for practicing the integration of skills, especially those needed to respond to events that don't often occur in the plant. It doesn't take a multi-million dollar simulator to achieve dramatic increases in learning, particularly during early stages of skill acquisition.

What's transfer of learning, and why is it important?

The transfer of knowledge, skills, and attitudes learned in training to performance on the job, which dictates how long it will take for personnel to perform their jobs proficiently.

When training quickly produces highly proficient performance on the job, positive transfer of learning has occurred. Negative transfer — meaning that job performance is actually worse than if no training had been provided — can also occur, as depicted in Exhibit 3-7.

Negative transfer is often attributed to differences between training and job situations. For example, when terms used in training are different than those used on equipment labels or in documents, personnel can become more confused and find it more difficult to learn the actual names than if they hadn't learned any beforehand. Or, if personnel practice in a simulator that doesn't adequately represent actual equipment in some important aspects, they may perform worse in job situations than if they hadn't received any practice at all. This is one of the reasons that fidelity of simulation, or realism, in the design of training devices receives so much attention.

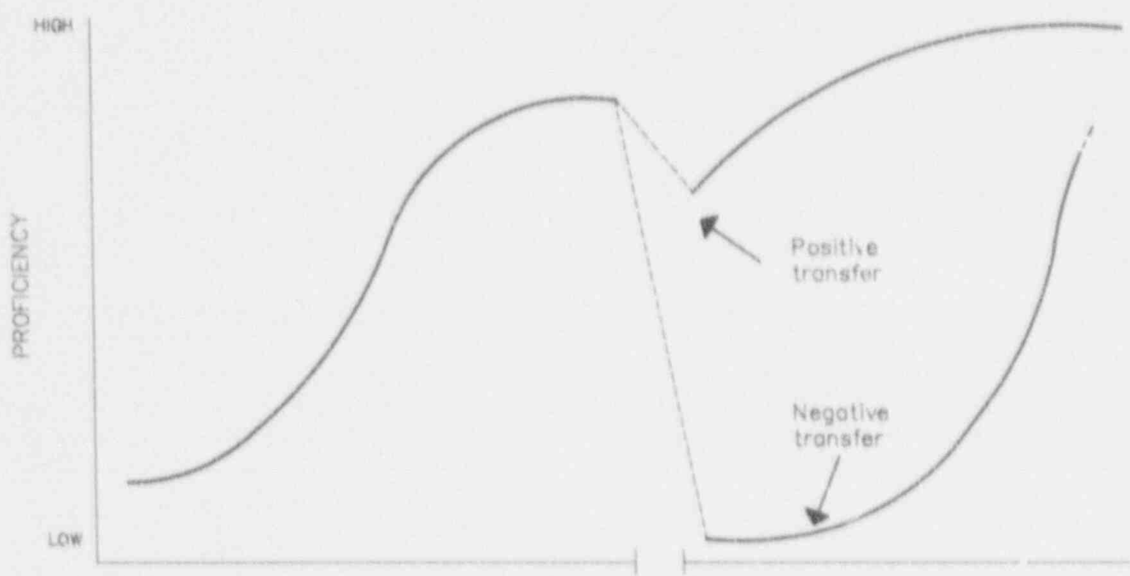

Exhibit 3-7. Positive transfer of learning facilities proficient performance, by negative transfer retards the development of proficiency.

As fidelity of simulation increases, positive transfer of learning generally increases, along with investment costs, as shown in Exhibit 3-8. As fidelity continues to increase, a point is reached where large gains in positive transfer can be expected for small increments in costs. This is followed by a point of diminishing returns, where costly increases in fidelity don't result in proportionate increases in positive transfer.

What's overlearning, and when is it justified?

Repeated exposures to situations already mastered, to help ensure retention of critical or infrequently used knowledge and skills.

Overlearning can be provided during initial training as well as through refresher courses. It's as simple a concept as "practice makes perfect" but calls for some sophistication to implement well. For example, one way of sustaining personnel attention during overlearning exercises is to operate a training device at faster than real time. The difference may not be that perceptible to personnel, but can reduce boredom, increase the performance challenge, and improve proficiency in certain skills.

How can human factors engineering help managers make sound decisions about training?

By better enabling management to evaluate training needs and by contributing to the specification of training devices needed to support acquisition of required skills.

Human factors applications in structuring work and defining policies to promote safe, productive performance include defining job performance measures. Properly constructed, these are far better measures of training effectiveness than training tests or subjective feedback from work supervisors. That is, tests given during training measure whether personnel have learned what was taught in a course, not whether they've learned to perform as their job tasks require. And, without the use of authorized job performance measures, supervisors are seldom able to provide the detailed feedback about performance deficiencies that's

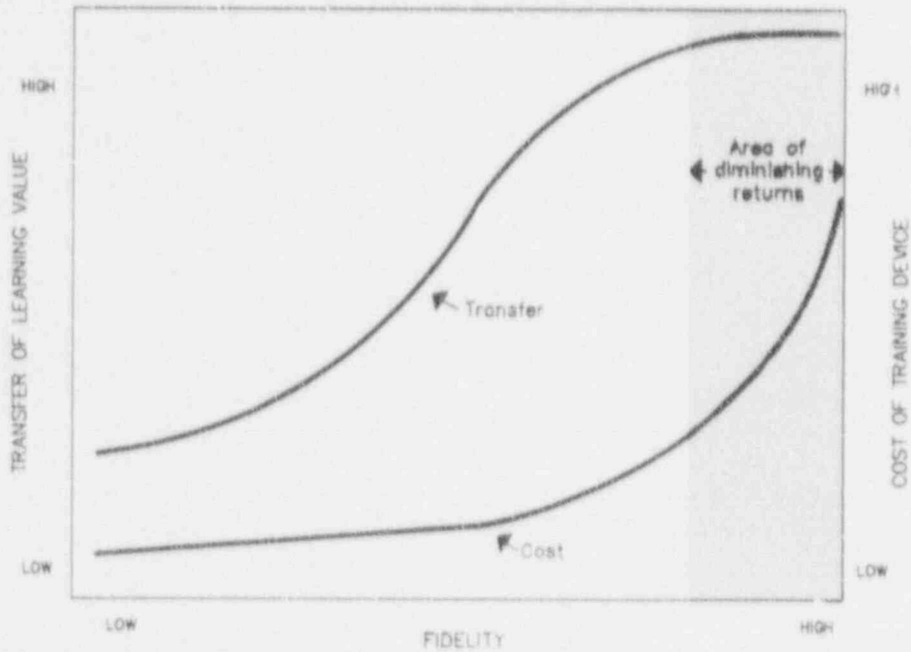

Exhibit 3-8. Relations among fidelity of simulation, transfer of learning, and costs.

needed for management to independently evaluate training effectiveness and initiate revisions.

In addition, human factors applications can address the psychological fidelity of training devices. Psychological fidelity refers to how realistic a training device seems to personnel, as opposed to how slavishly it duplicates inconsequential characteristics of actual equipment. Psychological fidelity can usually be achieved at less cost than physical fidelity, with no loss in positive transfer of learning.

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Section 3.3
Decisions about Documents

This section addresses the following questions:

What progressive decisions can managers make about plant documents?

What might prompt managers to consider improving documents that personnel use in performing tasks?

What distinguishes job performance aids from other plant documents?

What aspects of a task make it a candidate for document support?

Why is it important to establish and use a controlled vocabulary in documents?

What's a readability index, and how is one properly used?

What guidelines and conventions can be applied to help ensure document comprehension and ease of use?

Why should appropriate illustrations be used to support text?

Why is it important that documents be validated with users before being relied on in actual performance?

What innovations in document design hold promise for the nuclear utility industry?

How can human factors engineering help managers make sound decisions about documents?

What progressive decisions can managers make about documents?

Decisions helping to ensure that personnel not only have all the information they need, but can easily use it both in training and when performing tasks on the job.

Limitations in human capabilities dictate that some demands to remember and interpret information be reduced to help ensure reliable performance. Where training leaves off, procedures and other documents can go on to support performance if they relieve personnel of burdens in recalling information, transforming data, making decisions, and solving problems — without imposing needless demands of their own design.

Managers need to be advised about specific information requirements that should be satisfied by documents. They also want to be assured that the information is presented and packaged in ways that are compatible with human capabilities and that contribute to ease of use in the performance situation. Managers can also make sure that each document fulfills intended purposes during task performance by requiring that it be validated before approving it for use.

Several reports quote this comment of a plant technician with nuclear navy experience: "Plant documents are about 20 years behind the state of the art."[1,2,3] It seems that he's got a point. The industry has taken some steps to improve plant documents (as evidenced in INPO guidelines and EPRI reports), but management decisions account for large differences in the helpfulness of documents both within and across plants.

What might prompt managers to consider improving documents that personnel use in performing tasks?

Recognized problems that are implicated in:

- regulatory actions;
- safety-related events;
- breaches of quality control standards; and
- high costs of corrective maintenance.

Regulatory initiatives are one impetus for improving plant documents. For example, NRC has required nuclear power utilities to revise event-based Emergency Operating Procedures. Mandated symptom-based procedures prompt operators to initiate stabilizing procedures without first having to diagnose the causative event, as shown in Exhibit 3-9. Appreciating the general advantages of symptom-based procedures (apart from exceptional cases where procedural steps must vary by event), some managers have also seized the opportunity to improve procedures in more ways than required by regulation.

Investigations of safety related events suggest some of the ways procedures need to be improved. For example, INPO's SEE-IN (Significant Event Evaluation and Information Network) program recently identified deficient procedures as the leading contributor to human error in a sample of reported events. In addition, SEE-IN often identified failure to use procedures as a root cause of error. Other investigators, using the critical incident technique, have also found procedures a contributor to maintenance errors, accidents, and near mishaps.[3] These sources indicate that procedures are often inaccurate, out of date, confusing, and inaccessible or awkward to handle in performance situations.

Quality control inspections may similarly reveal instances where procedures aren't being followed largely because of document or facility design deficiencies. Line supervisors often find that operators and technicians have reasons rather than mere excuses for reluctance to use procedures. For example, having both hands occupied and soiled in performing a task discourages continuing use of a paper document, as does lack of adequate laydown space or lighting. In addition, personnel are often aware of instances where procedures are out of date or otherwise inaccurate, and so are reluctant to rely on them.

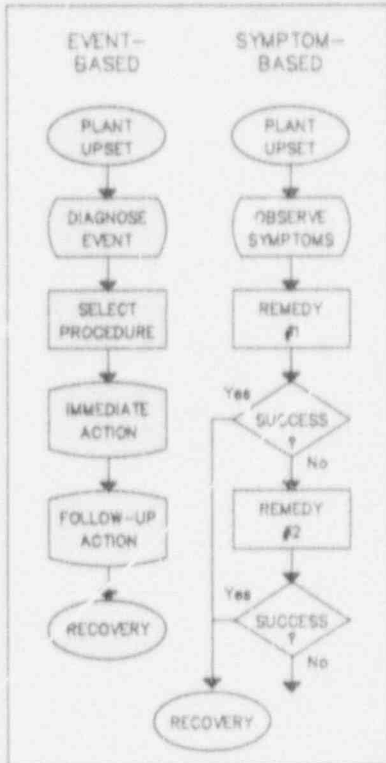


Exhibit 3-9. Symptom-based procedures prompt operators to take remedial action

Looking at the costs associated with corrective maintenance, a manager might well question whether documents could be designed to guide more effective fault diagnosis. If a utility provides little or no document support for fault isolation tasks, equipment downtime is needlessly extended. In their attempts to locate the fault, for example, technicians sometimes "repair" components that aren't related to malfunction symptoms, and sound components can become faulty as a result of inappropriate repair attempts. So job performance aids developed to reduce technician guesswork can help reduce high maintenance costs.

What distinguishes job performance aids from other plant documents?

The methods by which they're developed, including:

- content and conditions of use defined through task analysis;
- verification of content by subject matter experts; and
- validation of detailed design by representative users.

Traditionally, the term "job performance aid" suggested a little book with detailed information and illustrations intended to support performance of certain tasks or task steps. But the term has come to encompass not only procedures, but instruction sheets, troubleshooting guides, maintenance dependency charts, checklists, conversion tables, and even computer-driven expert systems that interactively present information to help guide task performance.

Other plant documents (e.g., equipment manuals, piping and instrumentation diagrams) contain more information than is directly relevant to specific tasks. Often, a document that attempts multiple purposes serves none well. For example, technicians complain about the inadequacy of equipment manuals that could have been designed as job performance aids, but weren't.

Instead, equipment manufacturers may use a language in manuals that's not easily understood by plant technicians and include few illustrations designed to support specific task actions. Some manuals address a class of various component models and rely on complex conditional statements to provide guidance for the specific model used in the plant. Manufactures may be willing to do the work of developing effective job performance aids, but charge more for them and must have detailed specifications to ensure that the utility gets the advantages it pays for.

What aspects of a task make it a candidate for document support?

In addition to task complexity and criticality, whether it:

- involves performing numerous steps in a prescribed sequence, with at least moderate speed and high accuracy and where errors of omission or commission are critical;
- depends on more detailed information than a relatively inexperienced person can reasonably be expected to remember;
- occurs infrequently;
- involves personnel in job positions with high turnover;
- requires exceptional problem solving capabilities if a sound approach isn't predefined; or
- produces deficient performance when existing documents are used.

Job performance aids may be useful for any task, but are particularly needed if the required standards of performance are likely to exceed post-training capabilities of personnel. Where the consequences of human error are severe, a procedure, instruction sheet, or checklist can help ensure reliable performance of even relatively simple, frequently performed tasks.

Why is it important to establish and use a controlled vocabulary in documents?

Because consistency lessens the likelihood that personnel will misinterpret the information.

A controlled vocabulary is a set of authorized terms that designers and personnel alike agree to use in preference to any synonyms. Plant documents should consistently employ the same authorized terms used in training and in labeling plant facilities and equipment. But documents have to refer to additional task-required actions, which requires a large controlled set of verbs and adverbs.

Consider a simple requirement to adjust a control. A person might be advised to push, activate, hit, trigger, depress, switch on, start the control, or half a dozen other possibilities — all supposedly meaning the same thing. When you consider all the actions personnel take, a free-wheeling vocabulary makes the likelihood of interpretation errors needlessly great.

What's a readability index, and how is it properly used?

A means of quickly identifying if the text of a document is likely to exceed the reading capabilities of personnel.

Readability indexes relate quantitative features of text — like number of syllables per word and number of words per sentence — to the demonstrated verbal capabilities of most people at differing educational levels. For usefulness in assessing plant documents, a readability index has to be adjusted to accommodate familiar words or phrases referring to equipment systems and operations. That is, jargon has to be appropriately weighted to reduce its impact. Otherwise, the score suggests a greater problem than actually exists (with unusual acronyms and polysyllabic terms like Feedwater/Condensate Differential Transmitter inflating the score).

Tests administered in schools nationwide establish the anchor points for most readability formulas. A readability score of 13.0, for example, indicates text that's difficult for most people who have no more than a high school education.

On the other hand, a readability score of 12.0, or less, offers little assurance that a person who's completed high school will be able to comprehend the material (or that the material can be comprehended by anyone). Far more enters into the question than the elements reflected in readability score. Expecting comprehension to improve by editing to a readability formula has been likened to lighting a match under a thermometer to warm up a room (i.e., the index value may improve, but the room won't get much warmer).[4] Better ways of improving the likelihood that personnel will be able to quickly and accurately interpret information in documents are to:

- use well-established guidelines and conventions;
- support text with appropriate illustrations; and
- validate the design under conditions of use with representative users.

What guidelines and conventions can be applied to improve document comprehension and ease of use?

Many commonly found in references on effective presentation of technical information.

Where linguists, cognitive psychologists, or human factors professionals have researched alternative conventions, findings generally support the accumulated practical guidance represented in style manuals and other references used by technical writers, editors, illustrators, and other document design specialists.[4] The importance of a controlled vocabulary has been suggested earlier, as have advantages of short, familiar words and fairly short sentences. Style manuals also typically provide guidance on, for example:

- eliminating vague or needless words;
- using simple sentences of normal subject-verb-object pattern;
- making equivalent items parallel in construction; and
- avoiding complex conditional statements and multiple negatives.[5]

More comprehensive references also address questions of typography, layout, graphic or tabular design, and overall format.[6] Guidelines about type fonts and contrast with shaded backgrounds indicate whether the user will be able to clearly see the information. Guidelines about the use of headings, space, lines of demarcation, and color or shading suggest ways of grouping information and directing user attention. Guidelines about the appropriate use of photographs, line drawings, tables, and graphs suggest ways of facilitating quick, accurate perception of information. Guidelines on the means of page numbering, the inclusion of indexes, glossaries, and even thumbnail tabs as well as on packaging and binding alternatives are intended to promote ease of document use.

From a human factors standpoint, it's worth noting that some conventions are so widespread, so well represented across the diverse documents a person deals with in a lifetime — from grade school texts to popular magazines — that they form the basis for common expectations. Expectations about documents influence whether personnel can locate information quickly and perceive it correctly as well as whether they accept and value the help a document can provide.

Why should appropriate graphics be used to support text?

Because they help people understand the accompanying text more readily — particularly novices or others who don't frequently perform the document supported task.

Although research on graphics is far from conclusive, it provides a basis for practical guidance on the effective use of photographs, line drawings, tables, charts, graphs, and other diagrams in plant documents. For example, photographs are more helpful than line drawings for locating specific objects within a busy context or for discriminating realistic differences (e.g., the qualitative deterioration that a technician has to detect in inspecting a component). Conversely, line drawings are superior for calling attention to detail if they represent the human's perspective when interacting with equipment. Line drawings with an exploded or cutaway view are useful for showing assemblages of components that technicians can't otherwise readily view.

For presenting data, graphs are easier to interpret than tables, with bar charts being generally preferred over line graphs. Logic tree diagrams have been found useful for presenting complex conditional instructions.

In addition to choices about the usefulness of different kinds of graphics, effective documents represent good choices about alternative ways of integrating text and graphics. For example, illustration callouts and procedural text can be fully integrated or put in corresponding top-bottom or side-by-side arrangements, as shown in Exhibit 3-10, or illustrations may be included as foldout pages at the end of a document. The question of which format works best has to be addressed by users as well as document designers.

Why is it important that documents be validated with users before they are relied on in actual performance situations?

Because other ways of determining if users can perform tasks by using a document are not very reliable.

The tryout situation can involve actual equipment, mock-ups, or simulators, but has to represent environmental conditions that affect document use and include a mix of representative users. The mix might include, for example, personnel who:

- are unfamiliar with the task or least qualified to perform it;
- have either completed training recently or some time before; and
- have lowest reading skills.

Measures obtained in the try-out include whether tasks steps are performed in the prescribed way, performance times, and success of task completion as well as opinions about document usefulness. These measures help identify specific document or facility design deficiencies. For example, a document deficiency might be that a special note or warning statement is given too late in the sequence of information to have precautionary effect. For another example, if information can't be seen under worst case viewing conditions, changes may have to be made in either the document, the facility design, or both.

What innovations in document design hold promise for the nuclear utility industry?

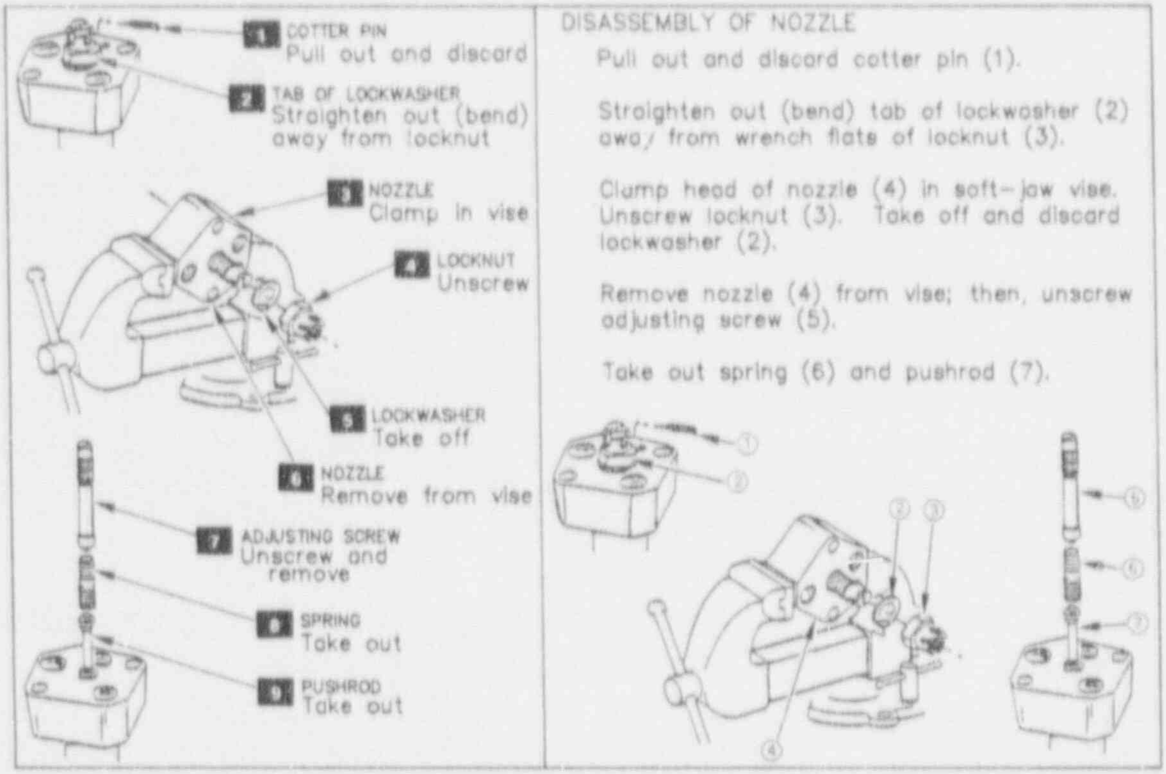
Machine readable documents that interactively respond to user commands.

Apart from paper, documents may exist on a machine-readable tape, disc, or chip. Information that used to be presented only on paper can now be advantageously presented on a CRT screen, plasma display, or other device used for presenting machine-readable information.

Advantages of machine-readable documents include:

- capability to tailor information to user inquiries;
- automatic provision of cross referenced information;
- instant reduction or expansion in information detail;
- ease of update; and
- new opportunities for performance tracking (with interactions recorded to help verify that procedural steps are being followed).

One disadvantage of presenting information on a CRT screen, however, is that it takes about twice as long to read the information, compared to reading speed with printed paper copy.



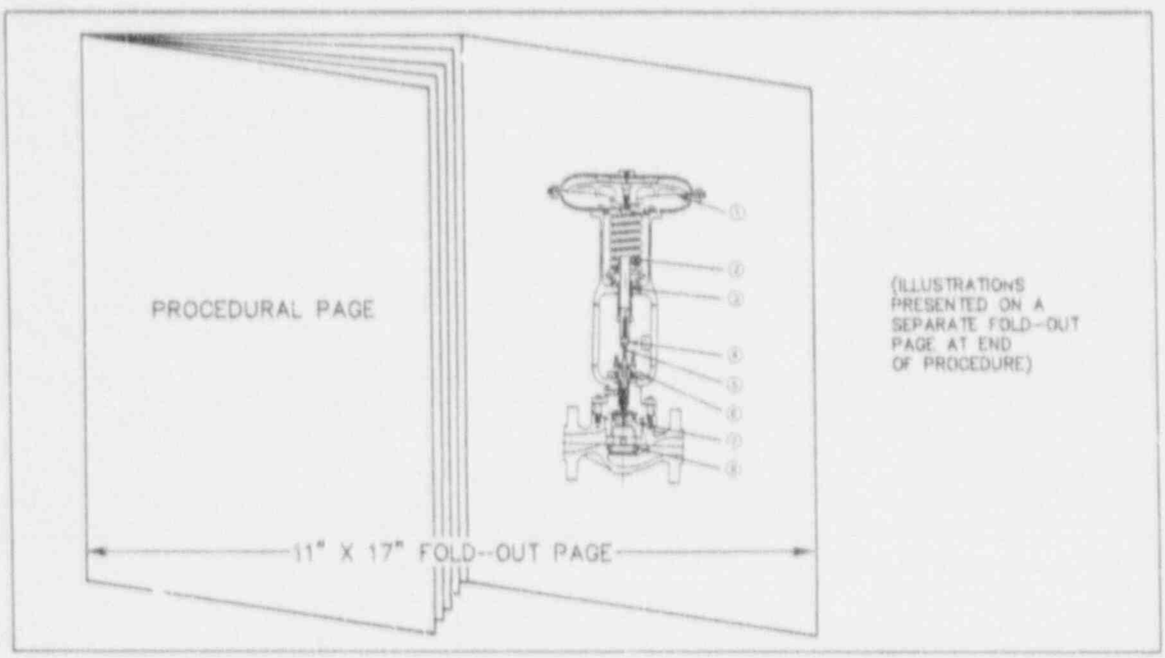


Exhibit 3-10. Alternative ways of integrating text and illustrations.

How can human factors engineering help managers make sound decisions about documents?

By helping ensure that:

- needs for documents are carefully evaluated and substantiated;
- document content is performance-based (i.e., on comparison of specific task requirements and the capabilities of personnel);
- conditions of use are reflected in document design;
- documents are validated before use in training or actual performance situations.

Task analysis methods identify document needs and help to define specific content as well as expected conditions of use. Human factors engineering also addresses questions of how information should be presented. Information about the sensory and verbal capabilities of personnel and their common expectations is applied in assessing design tradeoffs and establishing conventions. Where computer-generated interactive documents offer sufficient advantages to justify their development cost, human factors applications are particularly important to ensure user acceptance and ease of use. Validation techniques provide the evidence management needs that a document either accomplishes what's intended or needs further improvements.

References

1. Shriver, E.L., Zach, S.E., & Foley, J.P., Jr. *Test of job performance aids for power plants.* (EPRI NP-2676) Palo Alto, CA: Electric Power Research Institute, 1982.

2. Pack, R.W. et al. *Human engineering design guidelines for maintainability.* (EPRI NP-4350) Palo Alto, CA: Electric Power Research Institute, 1985.

3. Seminara, J.L., & Parsons, S.O. Nuclear power plant maintainability. *Applied Ergonomics.* 1982, 13,3, 177-189.

4. Felker, D.B. (Ed.) *Document design: A review of the relevant research.* Washington, D.C.: American Institutes for Research, 1980.

5. Felker, D.B. et al. *Guidelines for document designers.* Washington, D.C.: American Institutes for Research, 1981.

6. American Psychological Association. *Publications manual of the American Psychological Association.* (3rd ed.) Washington, D.C.: Author, 1983.

Chapter 4
INTERFACE DESIGNS
Decisions about Facilities, System Equipment, and Support Equipment

This chapter includes three sections that suggest how changes in the design of interfaces — *things people directly interact with* — help bring about improvements in plant performance. Section 4.1 discusses how facility design features like signs, access space, lighting, climate, and other environmental conditions impact on performance. Section 4.2 addresses system equipment designs, suggesting some choices that management has about increased use of advanced displays and improving personnel interactions with hardwired displays or controls as well as equipment throughout the plant. Section 4.3 indicates how support equipment like the communications system, protective gear, robotic devices, and various other machines and tools can better extend the capabilities of personnel.

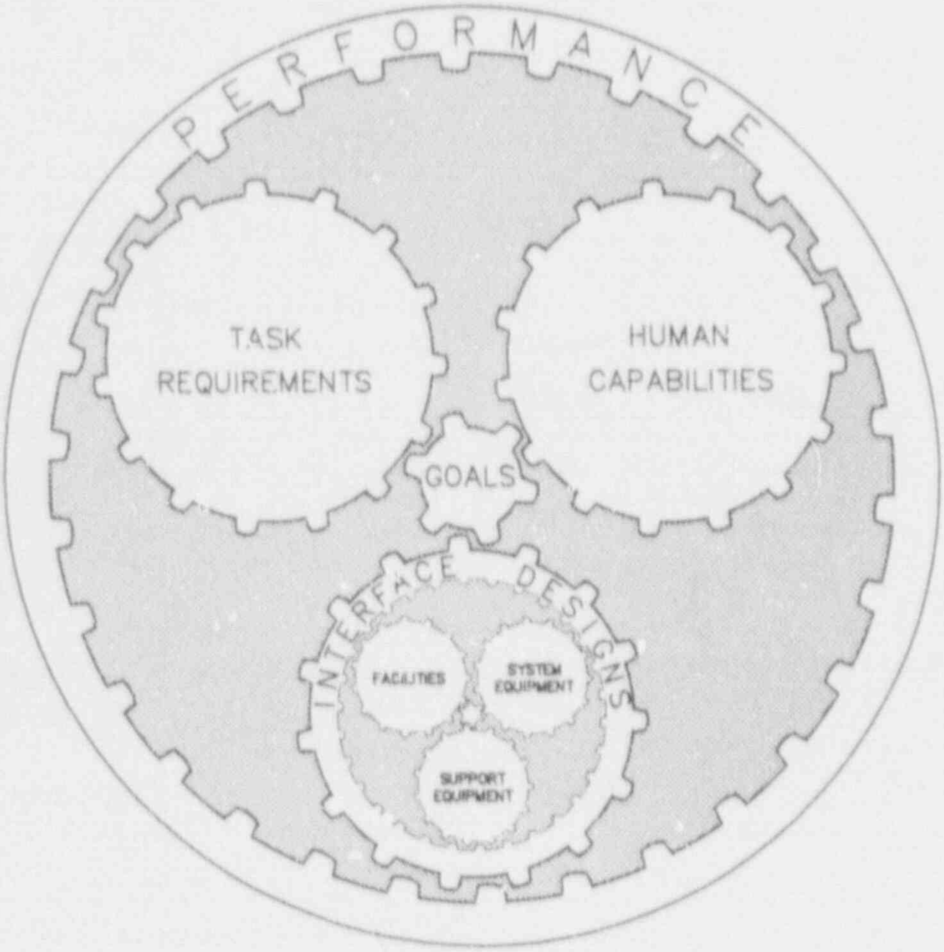


Exhibit 4-1. Interface designs reflect decisions about features of facilities and system equipment as well as needs for support equipment

Section 4.1
Decisions about Facilities

This section addresses the following questions:

What progressive decisions can managers make about plant facilities?

What might prompt managers to consider changing facility designs?

What impact can facility signs and placards have on personnel performance?

Why does information about the body dimensions of personnel enter into decisions about facility designs?

What techniques are useful in assessing facility layouts?

How can the decision to acquire an advanced control complex affect human factors in facility design?

How are lighting requirements likely to change when a mix of hardwired instruments and advanced displays are used in the same area?

What other environmental conditions are human factors concerns?

How can human factors engineering help managers make sound decisions about facilities?

What progressive decisions can managers make about plant facilities?

Decisions helping to ensure that personnel:

- can locate, travel to, reach, and move objects;
- can see or hear information; and
- are protected from environmental stresses and hazards.

Plant site, building, and workspace designs determine how efficiently personnel can locate and use plant documents, equipment, and tools. Facility designs also determine the range of environmental conditions (e.g., light, noise, climate) that affect personnel performance. Some equipment related conditions (e.g., radiation and extreme noise or temperatures) impose additional requirements on facility designs (e.g., accommodating use of protective gear and other support equipment).

Managers may have to live with some design constraints that were set by decisions made years ago. For example, few things are set more in concrete than containment building structures. But operating experience, human factors analyses, and technological advances provide a basis for utilities to make better use of available space and improve the environmental conditions that affect how personnel perform.

What might prompt managers to reconsider facility designs?

Recognized deficiencies and design change opportunities represented in, for example:

- regulatory actions;
- technological advances; and
- specific health and safety goals for personnel.

Regulatory actions sometimes call for changes in facility designs. Accommodating a mandated Emergency Operating Facility, a Technical Support Center, and additional control room displays, for example, has required many adjustments in facility designs. Whether these changes constitute improvement depends on existing constraints as well as how systematically the utilities identify and address the human factors considerations involved.

Managers' awareness of technological advances that offer potential solutions to some design dilemmas may lead to simultaneous changes in facility and equipment interfaces. For example, the size of the control room and number of operators have stayed the same in the last 10 years, but the number of discrete displays and controls has almost tripled, crowding panels and contributing to access problems in operations and maintenance tasks. Advances in computer technology now offer opportunities for utilities to not only conserve limited space, but relieve operators of burdens in remembering and integrating information from a number of discrete instruments.

Personnel injury and health statistics may also reveal where facility designs need to be improved. For example, reports about radiation exposures, heat stress, and incidents involving toxic chemicals are sources of management information about environmental conditions that deserve special attention.

What impact can facility signs and placards have on personnel performance?

Reducing confusion and delays as well as injuries and equipment damage.

People eventually learn their way around even the most inadequately labeled facilities. But orientation problems are better avoided by design than overcome through time-consuming trial and error learning. Besides new personnel and visitors, contractor personnel also need to locate various buildings and work areas quickly and easily. Otherwise, delays contribute to low productivity and high costs.

PLEASE

WALK UP ONE FLOOR

WALK DOWN TWO FLOORS

FOR IMPROVED ELEVATOR SERVICE

Exhibit 4-2. Human factors engineering asks "Will personnel be able to interpret the message quickly and correctly?" — the intended interpretation is provided in the references at the end of this section.

Human factors applications include ensuring that roads, parking areas, sidewalks, buildings, and workspaces are identified by signs that are easy for people to see and associate with known system and organizational functions. Helpful facility signs convey meanings that people already know or can easily learn and remember and are consistent with labeling of equipment, lines, and valves.

Warning and caution placards help personnel avoid injuring themselves or damaging equipment through improper use and also help protect the utility from lawsuits. Two human factors concerns are whether personnel can quickly and correctly interpret a message, like the one shown in Exhibit 4-2, and whether a placard has adequate attention getting value.

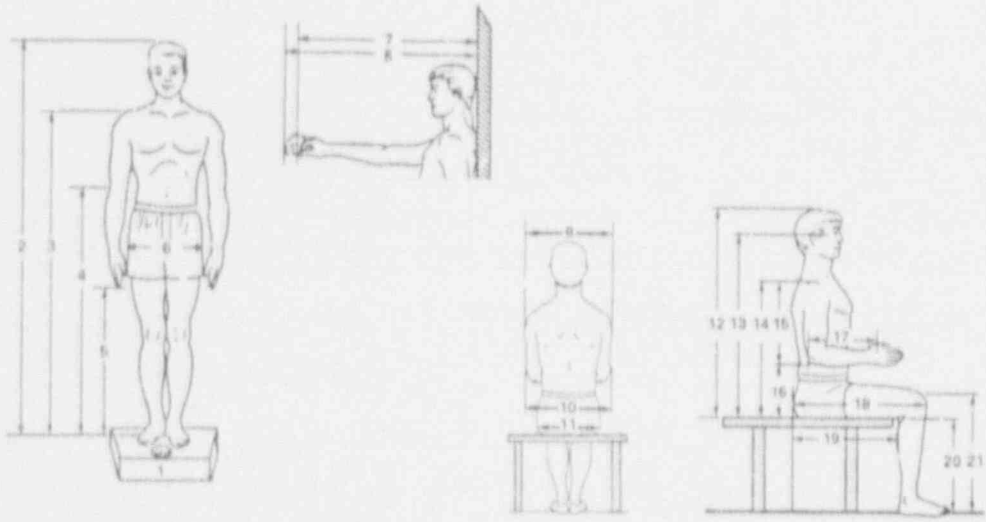
In addition to considering size, color, and placement alternatives, another way of increasing the attention getting value of critical information is to regularly replace existing placards with new ones of slightly different design. That is, people pay more attention to anything new in their environment than to things that have become familiar.

Why does data about the body dimensions of personnel enter into decisions about facility design?

Because facility designs have to accommodate and often compensate for individual differences within a plant's workforce.

Individuals with different body dimensions and muscular capabilities have to view things from a relatively fixed position, move about, lift objects and manipulate or transport them. Ideally, all plant personnel can easily see, reach, and interact with equipment, tools, and documents when performing tasks. But, realistically, accommodating 100% of any large group means incurring costs out of proportion to the benefits derived. That is, it may cost more to accommodate the few people at the extremes of a particular physical measure than it does to satisfy the needs of 90% of the workforce. (For example, to provide a chair that seats everyone comfortably at an eye level appropriate to viewing demands, the adjustment for seat height might have to be more than 10 inches. But a chair with only a 4 inch adjustment would generally do for 90% of the people.)

Given the tradeoffs involved in designing for people who're at the extremes, human factors applications typically follow what's known as the "fifth to ninety-fifth percentile rule." This means that an acceptable design is one that well accommodates 90% of personnel (both males and females). People who're below the fifth percentile or above the ninety-fifth percentile on relevant measurements, many of which are shown in Exhibit 4-3, have to "try harder" or, for critical task dependent capabilities, be screened out.



1. Weight
2. Stature
3. Shoulder height
4. Elbow height
5. Fingertip height
6. Hip breadth
7. Thumb-tip reach
8. Thumb-tip reach extended
9. Shoulder breadth
10. Forearm-to-forearm breadth
11. Hip breadth*
12. Height*
13. Eye height*
14. Shoulder height*
15. Shoulder-elbow length
16. Elbow rest height*
17. Elbow grip length
18. Buttock-knee length*
19. Buttock-popliteal length*
20. Popliteal height*
21. Knee height*

*Seated measurements

Exhibit 4-3. Some of the body dimension variables that enter into decisions about facility designs.[2]

What techniques are useful in assessing facility layouts?

In addition to applying checklists of human factors criteria to drawings or scale models, diagraming traffic patterns or links between key points in a facility.

In a link diagram, lines representing the movements of personnel during a task are superimposed on a layout drawing, as shown in Exhibit 4-4. The lines are often coded (e.g., by color, width, or number) to indicate the paths of different people, as well as the frequency, sequence, and importance of their movements.

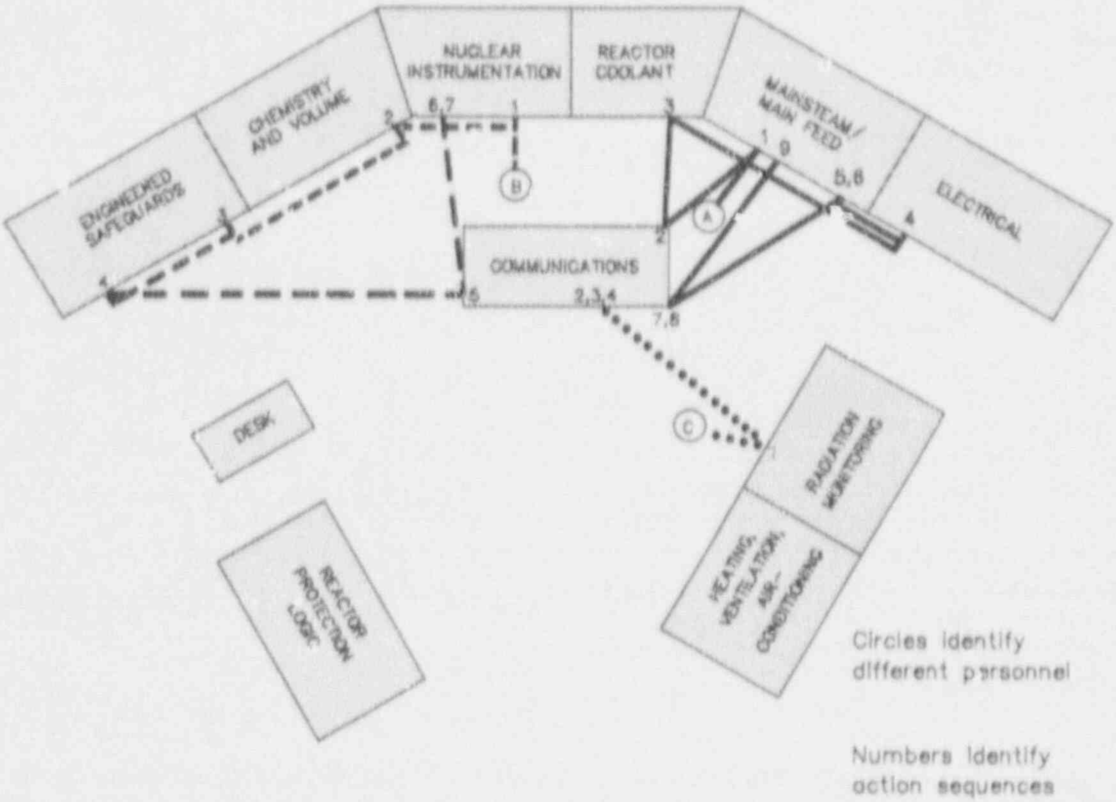


Exhibit 4-4. A sample link diagram for a control room, showing movements of three operators responding to a steam generator tube rupture.

Link diagrams provide a means of analyzing the efficiency a layout affords and determining ways of improving it. Main advantages of link diagrams are that they help managers as well as designers and the task performers themselves to visualize layout problems that could contribute to delays in performance or discourage personnel from performing inconvenient steps in a task.

How can the decision to acquire an advanced control complex affect human factors in facility design?

Concerns include:

- impact on task assignments among operators,
- placement within the existing configuration, and
- compatibility with other console profiles.

Advanced control complexes are being developed and marketed by various vendors. They typically offer not only generic process control programs and formats for computer-integrated displays but consoles designed to accommodate a number of display screens. Before anyone can begin to determine the workspace design implications, consideration should be given to how responsibilities are divided among operators in the control room.

Conventional consoles are typically configured in a modified circular, U, wing, or L shape, as shown in Exhibit 4-5. Each configuration offers advantages and disadvantages for accommodating an advanced control complex. Human factors recommendations have to reflect how the utility allocates task responsibilities among operators. If one operator performs monitoring tasks while other operators are responsible for control intervention, then ambient noise and distances involved in unaided voice communications are special concerns. If, on the other hand, both kinds of tasks are allocated by system to different operators, then unimpeded visual access and ease of physical movement are of greater concern. In either case, lighting requirements are likely to change somewhat.

Being aware of what the market has to offer in the way of advanced control complexes shouldn't keep a redesign team from specifying human factors requirements. Most vendors are able to be responsive to unique needs — whether they involve reducing console height to allow a see-over provision or raising the benchboard to accommodate sit-stand rather than fully seated operations. Utility managers need to be comprehensively apprised of human factors implications before agreeing to acquire an advanced control complex at a set price. Custom changes increase acquisition costs, but as the saying goes, "an ounce of prevention is worth a pound of retrofit."

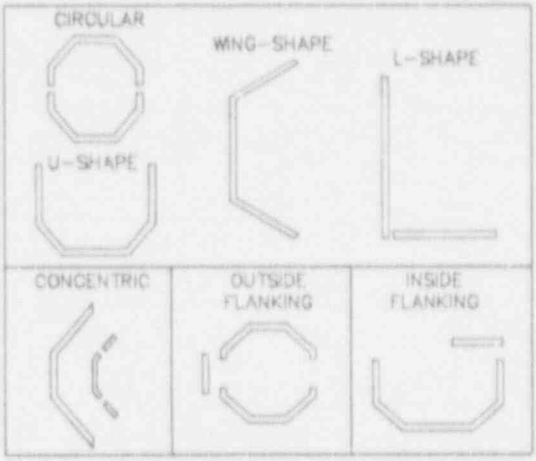


Exhibit 4-5. Conventional consoles are typically configured in modified circular, U, wing, or L shapes. Accommodating an advanced control complex within such configurations depends on how task responsibilities are assigned.

How are lighting requirements likely to change when a mix of hardwired instruments and advanced displays are used in the same area?

By becoming more complex, as lighting has to be tailored to competing demands for different levels.

Increased use of computer generated displays will pose a challenge in terms of conflicting lighting requirements. The relatively high level of overhead lighting required to see detail on meters and chart-recorders, for example, reduces the contrast typically needed when viewing advanced displays. Glare and background images reflected on the display screen can be highly distracting as well as fatiguing.

Fortunately, recent advances in lighting system technology enable variable adjustment of both the intensity and chromatic composition of ambient illumination and include diffusion techniques that can be applied to help eliminate glare. Use of hoods, filters, and screen tilting provisions are other ways to overcome adverse lighting effects.

What other environmental conditions are human factors concerns?

Besides lighting, main concerns are:

- noise;
- climate; and
- various conditions that could endanger personnel health and safety.

Human factors recommendations in lighting design take into consideration viewing distances and angles, the self-illumination characteristics of equipment interfaces, the information detail that people have to discriminate, and the surface properties of walls, floors, ceilings, and furnishings.

A human factors environmental survey is also likely to consider hearing distances, the placement of loudspeakers, noise characteristics of equipment that could produce disturbing sound interference effects, along with the acoustical properties of the workspace. Areas of the plant where exceptionally high noise could represent a hazard to the enduring hearing capabilities of personnel deserve special attention.

Climatic measures affect not only personnel comfort but performance reliability. Human factors applications are aimed at achieving climatic conditions within the zone most people find comfortable, as shown in Exhibit 4-6. High temperatures in some areas of the plant as well as adverse climatic conditions in unsheltered locations deserve special attention.

In addition, a traditional human factors concern has been the effects of hostile environments on human performance — in space and submarine applications, for example. This concern is appropriately extended to nuclear power plant facilities, which can be quite hostile outside the control room. In addition to risks associated with excessive exposure to radiation and high temperatures, other dangers include steam leaks, caustic or acid solutions, and slippery surfaces. Ways of combating these risks through facility design include posting placards, conspicuously coding equipment, and promoting use of protective gear and other support equipment by making it readily accessible.

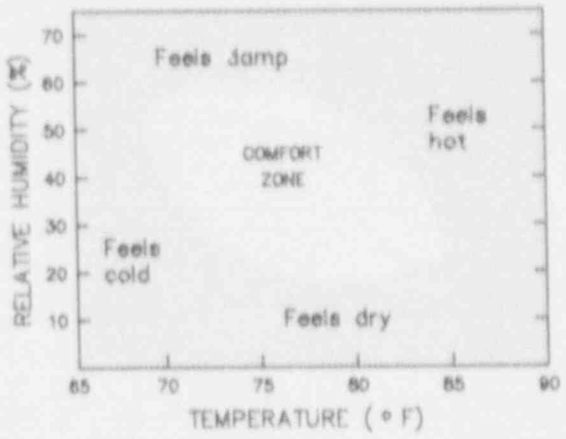


Exhibit 4-6. The comfort zone is determined by a combination of different temperatures and humidities.

How can human factors engineering help managers make sound decisions about facility designs?

By producing link diagrams, reporting results of environmental surveys, and applying other appropriate methods to identify facility design problems; by reviewing design change drawings and models for compliance with human factors criteria; and by recommending ways that discrepancies can be overcome.

Sometimes cost-effective solutions to facility design problems involve reallocating functions, changing the work structure, redefining personnel selection criteria, improving training, or providing better support equipment. For example, robotic devices can sometimes be used to avoid subjecting personnel to environmental hazards. Or technicians can receive enough skills practice on some tasks to reduce their average stay time in hazardous areas of the plant. When the ideal solution is not economically feasible, a systematic program of human factors engineering provides information that managers need to discriminate between a good alternative and a better one.

References

1. Chapanis, A. Man-machine engineering. Monterey, CA: Brooks/Cole Publishing, Wadsworth Publishing Company, 1965.

(The message intended in Exhibit 4-2: "This is a very busy elevator. Please use the stairs instead if you are going no further than one floor up or two floors down.")

2. Parris, H.L., & McConville, J.T. Anthropometric data base for power plant design. (NP-1918-SR) Palo Alto, CA: Electric Power Research Institute, 1981.

Section 4.2

Decisions about System Equipment Interfaces

This section addresses the following questions:

What progressive decisions can managers make about system equipment interfaces?

What might prompt managers to change equipment interface designs?

Why are display/control relationships important human factors concerns?

What labeling and coding techniques can be used to enhance equipment interface designs?

What techniques are useful in assessing panel designs?

What are computer generated displays, and how can they improve personnel performance?

Are there any pitfalls associated with use of computer generated displays?

How can alarm and annunciator designs be improved?

What innovations in system equipment design hold promise for improving plant maintenance?

How can human factors engineering help managers make sound decisions about system equipment interfaces?

What progressive decisions can managers make about system equipment interfaces?

Decisions ensuring that designs throughout the plant are consistent with human factors criteria and that innovations solve some old problems without creating new ones.

In plants nationwide, system equipment interfaces are in a state of actual or impending change. Industry leaders are forecasting, within the next 3 to 10 years, dramatically increased use of digital computers to process plant system data.[1] This trend will profoundly affect equipment interfaces designs in not only the control room, but the emergency operating facility, the technical support center, and local areas of the plant, as shown in Exhibit 4-7.

Today, digital computer technology offers many more options for satisfying task information requirements than existed when plants currently in operation were designed. Limitations in sensors, cabling, and electro-mechanical devices used to constrain management decisions about system equipment interfaces. But sensor improvements, along with digital transmission capabilities (i.e., over data highways within the plant and telephone lines to remote sites) enable rapid, reliable provision of precise data to diverse locations. In addition, the data can be transformed, integrated with other data, and displayed in virtually limitless ways.

What might prompt managers to change equipment interface designs?

Reasons for change could include:

- regulatory requirements and recommendations resulting from self-initiated surveys;
- objectives related to expansion of preventive maintenance programs; and
- opportunities arising through plant life extension programs.

The regulatory requirement to review and enhance control room designs from a human factors standpoint has made utility managers more aware of error-inducing design features. Many managers haven't confined

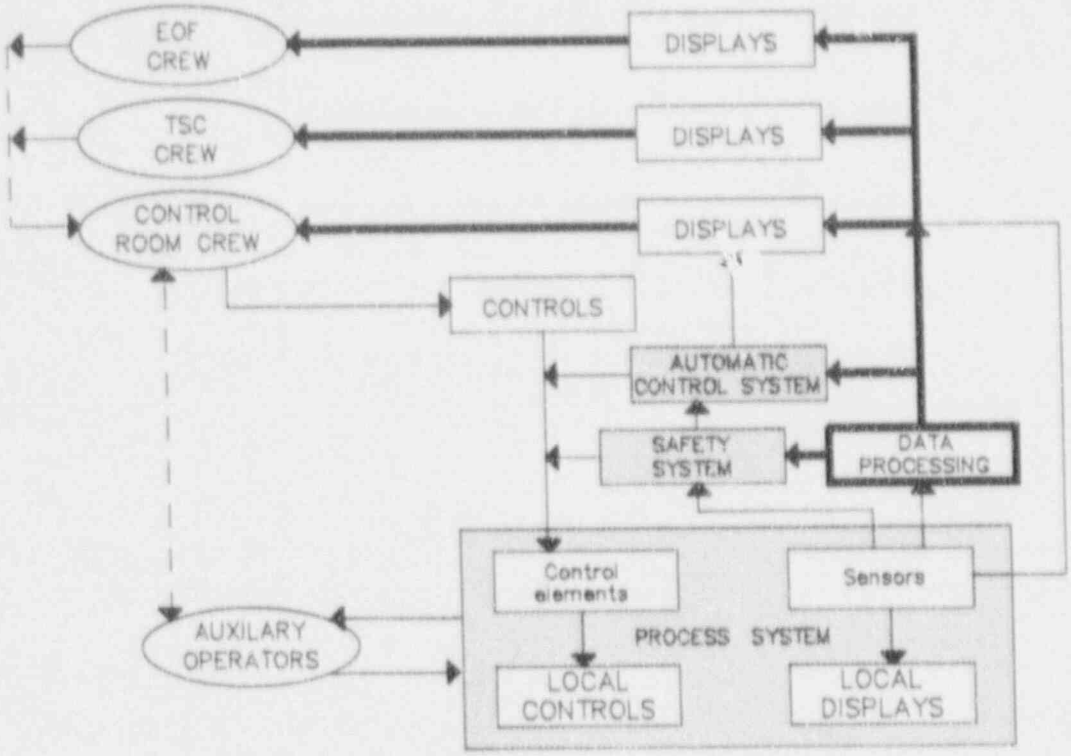


Exhibit 4-7. System equipment interfaces profoundly affected by use of digital computers to process system data (EOF, emergency operations facility; TSC, technical support center).

the panel improvement effort to the control room, but have independently initiated human factors surveys of panels in other areas of the plant, some of which are listed in Exhibit 4-8.

The utilities are also interested in improving predictive and preventive maintenance, some aiming for a maintenance distribution of 80% preventive, 20% corrective. The range of equipment monitoring devices that are available (e.g., infrared thermography, vibration, and leak detection devices) clearly allows for better prediction of impending equipment failures, provided that human factors concerns in the use of portable or installed automatic varieties (e.g., access, labeling of measurement points, means of display) are adequately addressed.

Plant life extension programs afford other opportunities to improve interface designs at the same time engineering changes are made to system equipment. Improvements are likely to mean greater reliance on highways of computer processed data and less on voice communications to transmit information about system equipment operations.

MAIN CONTROL ROOM CONSOLES	LEAK RATE TEST PANEL (CONTAINMENT)	WATER TREATMENT SYSTEM CONTROL PANEL
RADIATION MONITORING SYSTEM CONTROL PANELS	HEATING AND VENTILATION CONTROL PANEL	CHEMICAL ADDITION PANEL
REMOTE SHUTDOWN CONTROL PANEL	SUBSTATION ELECTRICAL PANEL	BORIC ACID
	COMPUTER CONSOLE PANEL	LITHIUM HYDROXIDE
FUEL TRANSFER CARRIAGE CONTROL PANEL	LIQUID AND GAS WASTE PANEL	HYDRAZINE
		RADIATION WASTE PANEL
FUEL HANDLING BRIDGE CONTROL PANEL	WASTE EVAPORATOR CONTROL PANEL	WASTE DRUMMING CONTROL PANEL

Exhibit 4-8. Panels located outside the control room that are candidates for design enhancement.

Why are display/control relationships important human factors concerns?

Because display/control relationships that are consistent with the expectations and needs of personnel reduce the likelihood of error in control adjustments.

People have expectations about: spatial relationships of instruments; their direction of movement; and the amount of movement needed when manipulating controls to effect a change in displayed values.

When interface designs aren't compatible with common expectations, like those shown in Exhibit 4-9, personnel find their tasks more difficult and are more likely to make mistakes.

EXPECTED DIRECTION OF MOVEMENT RELATIONSHIPS		
DIRECTION OF CONTROL MOVEMENT	SYSTEM EQUIPMENT COMPONENT RESPONSE	DIRECTION OF DISPLAY MOVEMENT
Up, right, away from operator, clockwise	Actuate/start, increase in quantity, open, extend	Up, right, clockwise
Down, left, toward operator, counter-clockwise	Deactuate/stop, decrease in quantity, close, retract	Down, left, counter-clockwise

Exhibit 4-9. Examples of common expectations about display/control relationships.

What techniques are useful in assessing panel designs?

Besides comparing design features against checklists of human factors criteria, diagramming personnel interactions with instruments across panels or within a single panel.

Operational sequences of behaviors during a task can be diagrammed, as shown in Exhibit 4-10, to depict the nature of interactions among personnel in various locations and with instruments on different consoles. The distribution of instruments across panels can then be analyzed for excessive communications or movement demands, and changes can be made to increase performance reliability and efficiency. Changes may be in the assignment of responsibilities to individuals or in the location of selected instruments.

Specific interactions with displays and controls on a single panel can also be diagrammed, to identify eye-hand movement patterns during task performance. The arrangement of instruments on a panel can then be analyzed to determine whether the sequence of task behaviors can be better reflected within the overall layout approach (i.e. grouping by system functions, mimic flow). Also, co-location of related displays and controls in the same viewing field can be assessed.

What labeling and coding techniques can be applied to enhance equipment interface designs?

So called "paint, label, and tape" techniques that are relatively inexpensive but can dramatically reduce the perceptual demands on personnel.

The expense of rearranging instruments on panels isn't always warranted by the performance difficulties associated with human factors discrepancies. Some difficulties can be eased by design enhancements that facilitate accurate perception of display/control relations as well as identification of each individual instrument.[2]

"Painting" or color coding the panel surface is an effective way to indicate a relation between displays and

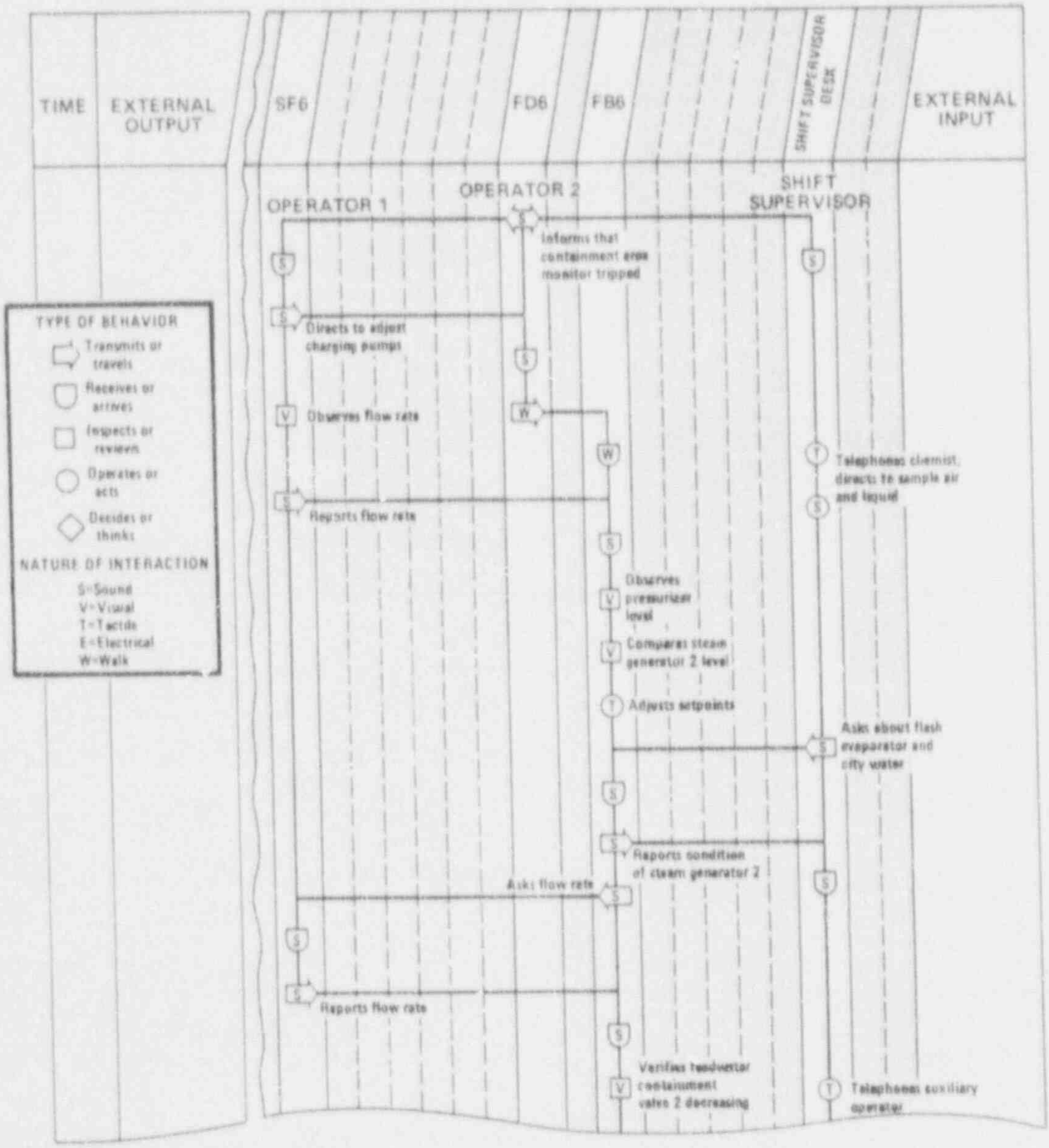


Exhibit 4-10. Simplified portion of an operational sequence diagram, depicting task behaviors at four control room locations in response to a steam generator tube rupture.

controls located on different panels or panel segments. Areas of color shading can also be used to make groupings of related instruments on a panel more apparent. Labeling enhancements usually involve reflecting system, subsystem, and train or loop hierarchies in labels, with associated size coding, that eliminates the need for repetitive content in individual instrument labels. Used consistently, hierarchical labeling techniques not only reduce perceptual demands but the likelihood that personnel will misidentify individual instruments. Tape used to indicate the relationships of instruments on panels can also incorporate codes (e.g., color, width) to facilitate accurate perceptions. The difference that effective use these techniques can make is indicated in Exhibit 4-11.

Paint, label, and tape techniques can also be used to enhance other equipment interfaces located throughout the plant. Color coding of hazardous equipment (e.g., high pressure steam pipes) helps personnel recognize and protect themselves against possible dangers. Improved labeling helps technicians avoid performing unwarranted work on misidentified components.

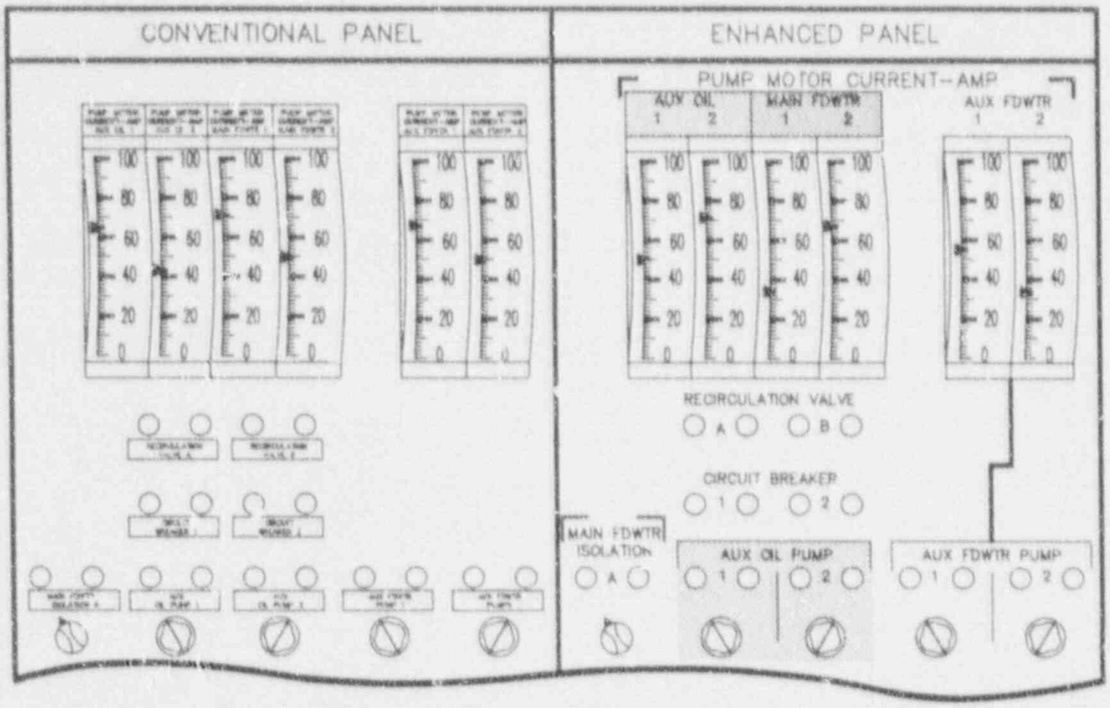


Exhibit 4-11. Comparison of a panel design before and after paint, label, and tape enhancements.

What are computer generated displays, and how can they improve personnel performance?

Representations of sensor signals that have been processed by a computer and then presented on a display screen to relieve personnel of burdens to view, remember, and integrate data from diverse hardwired displays.

Computer processing can include:

- comparing and combining related measures;
- alerting personnel to the significance of deviations from operating specifications;
- translating data into measures that are almost immediately useful to personnel;
- projecting emerging trends; and
- applying decision algorithms to provide prompting to personnel.

With appropriate hardware, programming, and page design, computer generated displays can reduce capability demands on personnel by presenting information that's tailored to specific task requirements.

Are any pitfalls associated with use of computer generated displays?

Several, including lack of display/control integration and limitations in the amount of information that can be displayed at one time.

Existing regulations prohibit digital transmission of control signals to safety related equipment. Otherwise, operators could both receive information and transmit control signals by using an integrated system. Given regulatory constraints, use of computer generated displays will result in what's been called a "hybrid system" (i.e., a combination of computer generated displays and various hardwired instruments).[3]

In cases where displayed information guides precise control adjustment, hardwired displays may still have to be located near controls. Depending on how task duties are distributed, operators could have to time share between computer generated displays and those associated with specific controls. In other cases, lack of usual spatial relationships between displays and related controls will increase the importance of explicitly assigning monitoring and control responsibilities to different operators and using team training as a means to compensate for design constraints.

The amount of information that can be presented at one time on a display page is restricted by the size and resolution of the screen. Unless an operator has parallel access to several screens, obtaining more than one page of information means serially calling up other pages for viewing, which could create problems. For example, operators could have a problem identifying which page to call up next. Or, they may have trouble holding in short-term memory information that's been removed from the screen while waiting for the next screen to appear. Where rapid operator response is required, delays in generating screens may be critical. But display page limitations and serial access don't have to be problems if designs are dictated by information requirements and application of human factors principles.

Display pages can be constructed to present only the information that's needed to satisfy specific task requirements. For example, schematic or mimic pages used to monitor overall system operations can provide hierarchical access to other pages. Tabular or trend formats providing detailed information can, for example, be called up as windows superimposed on a schematic page, as shown in Exhibit 4-12. Or detailed information can be presented on separate pages, with menu access programs allowing easy return to the previously consulted schematic page.

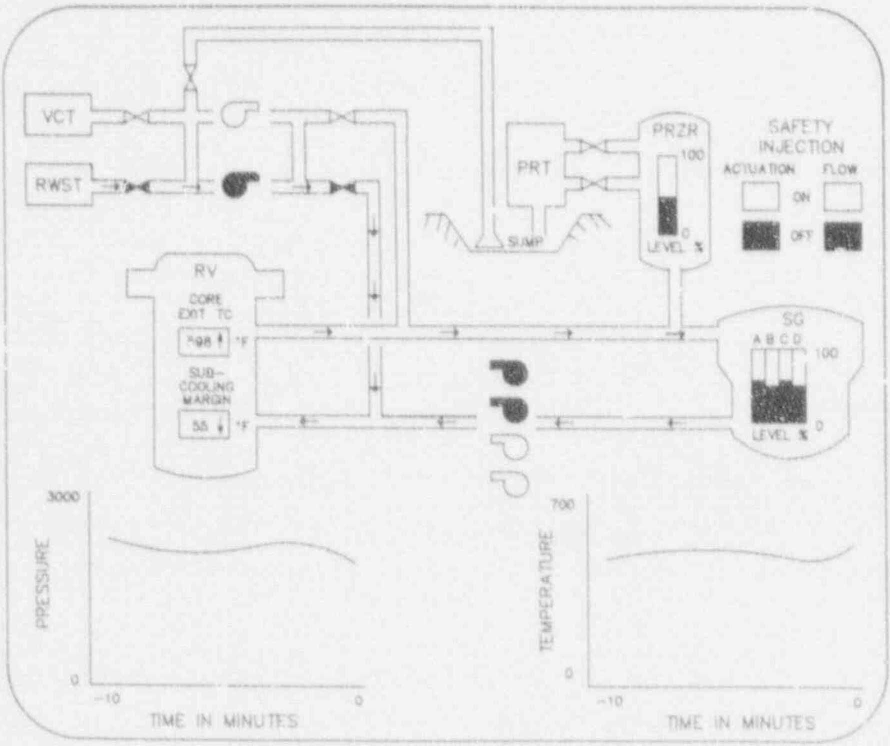


Exhibit 4-12. Sample of a schematic display with selected trend information superimposed at the bottom of the page.

How can alarm and annunciator designs be improved?

By using a task relevant basis to select and prioritize alarm sources, and by using computers to logically combine signals and present coherent alarm information to personnel.

The fundamental problem with alarm and annunciator systems in nuclear power plants is that more alarms can be activated at any time than personnel can fully attend to. Experienced personnel in these situations rely on their pattern recognition capabilities, but may ignore alarms that don't fit the known patterns. Conventional hardwired alarm and annunciator systems can be enhanced to better support the ways that personnel interact with them.[4] But innovative computer-based alarm reduction and presentation strategies should be systematically evaluated in relation to use of new emergency procedures as well as other computer generated displays (e.g., safety parameter, disturbance analysis display systems) in the control room.[5]

What innovations in system equipment design hold promise for improving plant maintenance?

Equipment performance monitoring devices that detect "signatures" of incipient malfunctions.

Embryonic malfunctions may be signalled by changes in temperatures, vibration, noise, magnetism, or a variety of other measures developing over a long time. For example, gradual increases in bearing temperatures over several shifts suggest impending pump bearing malfunctions.

Technicians have difficulty detecting signs of impending equipment failure when they lack adequate access to the equipment or the cues associated with the failure are too subtle for easy recognition. Similarly, operators may have trouble detecting malfunction signatures sufficiently in advance of an actual malfunction unless displays are designed to promote early recognition. Where personnel can't reliably detect early signs of a malfunction, an equipment performance monitoring system can be implemented as part of an overall preventive maintenance program.

How can human factors engineering help managers make sound decisions about system equipment interfaces?

By helping to define information and response requirements, by specifying human factors criteria for interface design changes, and by progressively evaluating designs as they are developed.

Information and response requirements derived from task analysis establish baseline specifications for computer generated display systems.

Some basic principles and criteria for the design of computer generated displays are represented in NRC guidelines.[6] But better ways to meet recognized design challenges are continually being discovered. For example, angle of inclination coding, as shown in Exhibit 4-13, is an innovative way of augmenting numerical data with trend information. That is, the angle of inclination represents the average trend over a fixed time and the position of the pointer indicates the relation of the current value to acceptable limits.

Some human factors guidance for developing and evaluating computer generated display system designs has been provided by EPRI.[7,8] Major evaluation concerns are compatibility of displays with the sensory and perceptual capabilities of expected users, user acceptance and understanding of complex designs, and display effectiveness in helping the user perform assigned tasks.

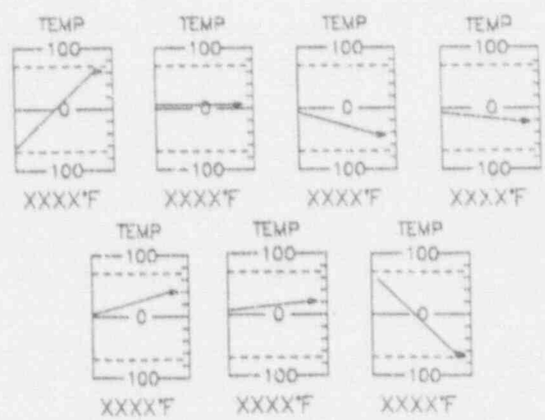


Exhibit 4-13. Pointer, along with the numerical readout at the bottom, shows the current value in relation to high and low prealarm values; The angle of pointer inclination indicates average trend.

The part task and full scope simulations recommended for use to evaluate computer generated display designs can also be used in training.

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Section 4.3

Decisions about Support Equipment

This section addresses the following questions:

What progressive decisions can managers make about support equipment?

What might prompt managers to consider changing support equipment?

How is information about biomechanics useful?

What human factors information plays a prominent role in effective communications?

What human factors applications can improve the safety of material handling devices?

How can the decision to acquire robotic devices impact on task requirements?

How can human factors engineering help managers make sound decisions about support equipment?

What progressive decisions can managers make about support equipment?

Decisions extending human capabilities, reducing physical hazards, and making task performance easier and more comfortable.

Support equipment is a catch all term for any device that increases what people are able to do safely and comfortably. It includes

- ladders, and platforms;
- material handling devices, such as hoists, cranes, and elevators;
- tools and test equipment;
- communications devices;
- protective gear and robotic devices that remove personnel from hazardous environments; and
- furniture and storage containers.

In plants currently operating, some support equipment might have been acquired as an after thought rather than being treated as an integral part of plant development.[1] It's been reported, for example, that technicians often interact with system equipment as though it were a jungle jim, using piping as a foothold or hoist point. Similarly, it's not unusual to see personnel waiting for a lull in a party-paging system so they can talk, or long lines of personnel waiting at tool cribs to obtain special tools.

Decisions to change support equipment or to better select equipment for use by plant personnel can increase safety and productivity. Reductions in man/rem exposures, industrial accidents, and miscommunications can make a plant a safer place to work. Reductions in unnecessary tools and difficult to use test equipment as well as improvements in furnishings and storage access will make plant personnel more productive.

What might prompt managers to consider changing support equipment?

A number of opportunities that may arise when decisions related to system equipment are made, but among the other reasons for looking at support equipment are.

- concern about industrial accidents and related insurance costs,
- awareness of advances in the design of protective gear and robotics, and
- pressures to reduce operating costs.

Falls and improper use of material handling devices are among the leading causes of serious industrial accidents. More frequent, but also less serious accidents occur from people slipping, tripping, and being exposed to hazardous electrical, mechanical, and chemical conditions. While all plants have plant safety personnel who try to reduce the occurrence of accidents, sometimes they overlook information about human limitations. For example, safety personnel are likely to insist that guardrails be provided on platforms, as required by Occupational Safety and Health Administration regulations. But handholds that would provide support to personnel while performing tasks may not be provided.

Improvements in protective gear and robotics are being made at a rapid rate. Newly designed protective gear (e.g., hard hats, clothing, eye and ear protectors, shoes, and gloves) give management an opportunity to increase personnel safety, comfort, and productivity. Similarly, advances in robotic designs can relieve personnel from performing repetitive or visual inspection tasks in hazardous environments.

Labor hours wasted when personnel have to wait for special tools and test equipment, gain access to communications, or move material handling devices to locations where they can be used all contribute to increased operating costs. Similarly, costs of performing maintenance in contaminated areas could be reduced by employing "fish-tank" viewing windows, long-handled tools, improved cooling garments that extend stay times, as well as remote manipulator devices.[1]

How is biomechanical information useful?

In helping to ensure that support equipment is compatible with how the body is constructed.

A biomechanical view of the human body sees bones articulated at joints as levers that move and transmit force. The amount and direction of motion for different body parts is determined by the structure of joints. The force that can be exerted in different directions is determined by bone and muscle structures. Biomechanical information includes the range of movement in different directions along with the forces resulting from such body movements. It is usefully applied in the design of support equipment such as platforms, tools, and protective clothing.

Platforms designed to allow personnel to get close to an object and to use their leg muscles when exerting force could reduce the need for material handling equipment. But, if personnel have to exert forces primarily by muscles above the waist and with the arms extended, they won't be able to exert much force, as illustrated in Exhibit 4-14. A requirement to lift objects weighing more than 20 - 35-lb from an arm extended, over head position could cause the objects to be dropped by some personnel.

Tools and protective clothing should be selected with the biomechanical aspects of the human body in mind to relieve demands for making motions or exerting forces that exceed capabilities. For example, tools requiring personnel to exert force toward the center of the body should be given preference over those that require force to be exerted to a side away from the center of the body. Tool selection is particularly important when consideration must be given to providing tools that allow the fastest, safest actions possible. An example of human factors applications to tools used on bolts in contaminated areas is provided in an EPRI report.[2]

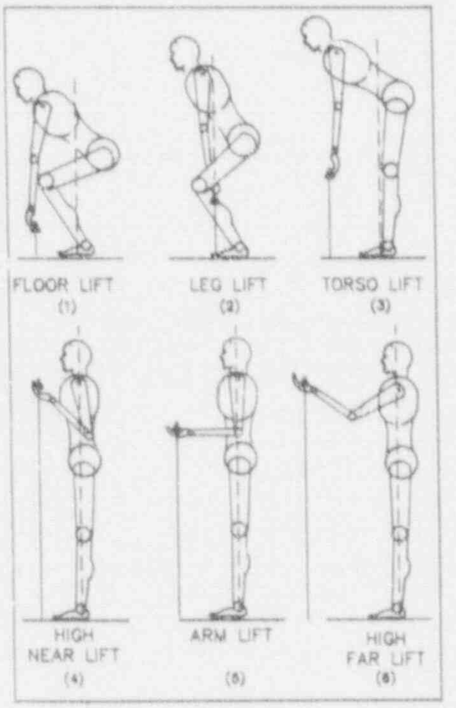

Exhibit 4-14. Lifting can be done with greater force when people can use both arm and leg muscles and objects are close to the body. Lifting capabilities are in descending order with (1) being highest.

Some protective clothing may add more bulk to articulated parts of the body than others. Protective clothing that permits the freedom needed to assume postures required by tasks should be given preference over clothing that restricts movement particularly at the neck, shoulder, arm, and crotch. Reductions in mobility and dexterity, as well as visibility when eye covering is required, can also reduce the number of things personnel can be expected to do when wearing protective clothing.

What human factors information plays a prominent role in effective communications?

Information about hearing and speaking capabilities as well as ways of enhancing communication capabilities.

At one end of any communications system you have a person speaking and at the other end you have a person, or people, listening. For a communications system to be effective, equipment characteristics have to be compatible with human capabilities. For example, a communications system with a bandwidth of 300 - 3400 HZ takes advantage of a person's normal hearing sensitivity and speaking ranges, as illustrated in Exhibit 4-15. Other equipment characteristics affected by human capabilities include dynamic range, phase shift, attenuation distortion, and signal loss.

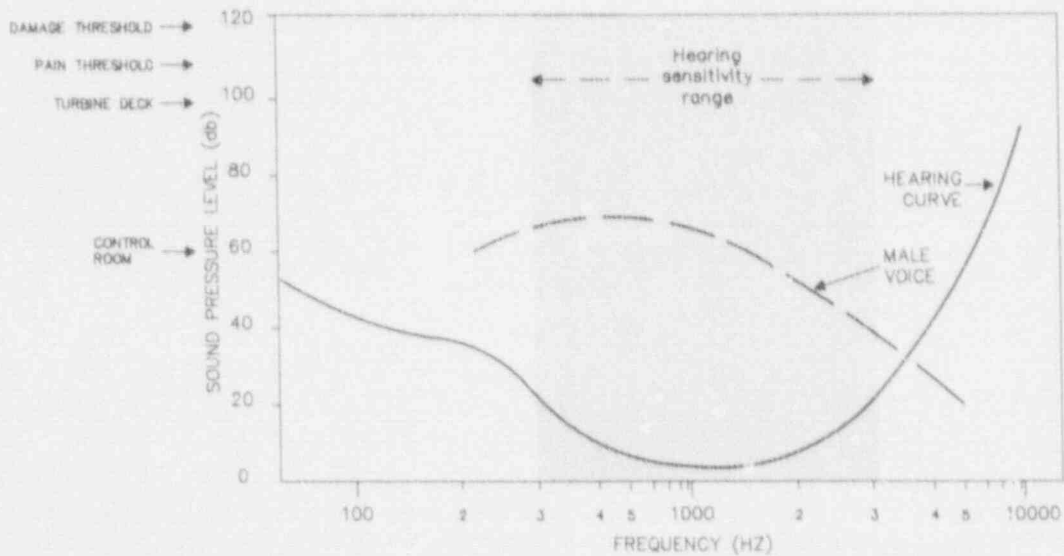

Exhibit 4-15. Relationships of hearing sensitivity and voice ranges, along with typical sound pressure levels that have implications for communications

A number of options are available for enhancing speaking and hearing capabilities. For example, noise shields and noise canceling microphones can be used to enhance speech in a noisy surroundings. Hearing, particularly in noisy places, can be improved by techniques like "peak clipping." Peak clipping emphasizes sounds in consonants relative to vowel sounds, increasing the distinction between words with the same vowel sounds (e.g., "no", "go"). There are non-equipment options as well. For example, speech can be improved considerably if speakers use communications protocols and a controlled vocabulary. A person saying "affirmative," for instance, is less likely to be misunderstood than one saying "yes," "yeah,"or "uh-huh."

The point is that human factors applications in voice communications systems can help take the "mis" out of intraplant miscommunications. Useful guidelines have been provided in EPRI reports.[3,4]

What human factors applications can improve the safety of material handling devices?

Applications of human factors criteria to identify design discrepancies.

Checklists and recommendations that may be usefully applied when evaluating material handling device designs have been provided.[5] Correcting design discrepancies identified from a survey of material handling devices could remove error inducing factors. Where it may be very expensive to correct design discrepancies, relatively low-cost warning placards could be provided to alert personnel to potential problems. For example, one forklift designed before Occupational Health and Safety Administration standards went into effect had a control that did not return to a neutral position when the operator's hand was not on it. A warning placard placed near the control now warns operators of this feature, too late for the operator who was standing on the lift who couldn't reach the control before being crushed against the roof.

How can the decision to acquire robotic devices impact on task requirements?

By relieving personnel from some burdens while also presenting new ones.

Robotic devices perform operations that are similar to tasks performed by personnel. For example, robotic devices may manipulate and move objects or even weld a pipe. How robotic devices are controlled have implications for not only what a robot can do, but what burdens are placed on operators and technicians.

Some robotic devices are controlled automatically, without operator intervention. Such devices are used cost effectively for highly repetitive tasks, where there is little variation in the operations performed. When self-contained, automatically controlled robotic devices are located in a contaminated environment, installation and repair can be a time-consuming and potentially hazardous task. It may be cost effective to locate all but the most reliable parts of such devices in a remote area, outside the hostile environment.

Other robotic devices require control signals from operators to perform some operations but they automatically perform others. For example, certain remote manipulators require an operator to guide a picking device to an object and the device automatically seizes the object and moves it to a different location. Similarly, some zone surveillance cameras automatically pan to selected areas but operators have control over zoom lense settings. Burdens on operators can be reduced appreciably when steps are taken to enhance the cues operators need to produce control signals. For example, painting a grid on the wall behind a picking device helps operators position the device. In surveillance devices, using a light blue color that the TV camera is insensitive to can enhance contrast and, when used on floors, helps leak detection.

Other robotic devices are operated only by control signals provided by operators. The burden on operators for remotely controlled devices is determined by how well information and response requirements have been satisfied. Recent advances in the design of control systems for such devices permit versatile, accurate performance by operators.

One remotely controlled robotic device, the "surveyor," provides zone surveillance in a radioactive environment. It is able to climb and descend standard stairs, surmount short obstacles, and maneuver around piping and hangers when guided by relatively inexperienced operators. A zoom camera allows gauges to be read at distances up to 30-ft. The device is also equipped with radiation, temperature, humidity, and noise sensors.[6] It reduces requirements for personnel to perform tasks in a hostile environment while, at the same time, providing more information about what is happening in the environment than personnel can typically provide.

How can human factors engineering help managers make sound decisions about support equipment?

By contributing to cost/benefit analyses related to changing existing support equipment designs, providing specifications in "requests for proposals" that address design features enhancing personnel performance, and participating in the selection of support equipment.

Changing existing support equipment can reduce demanding task requirements which, in turn, can reduce the need to select personnel with unusual qualifications and provide extensive training. Questionnaires and interviews, coupled with results of surveys, can be used to identify demanding support equipment. Task analysis methods can identify how possible design changes will impact performance. The cost of making the changes can then be assessed in light of their impact on performance effectiveness.

When a utility is planning to procure a major piece of support equipment, such as a crane or hoist, specifications reflecting human factors criteria could be included in the procurement package. While vendors may charge a little more for devices that satisfy human factors criteria, the additional cost could pay dividends by avoiding problems with the device during plant operations. For example, the results of a traffic pattern diagram could establish maximum dimensions for a material handling device that has to be moved to various locations in the plant. Failure to consider such dimensions could either restrict the locations that the device could be moved to or require significant changes to aisle or overhead structures.

Human factors applications can ensure that conditions of use are considered along with other criteria when hand tools, test equipment, furniture, and storage containers are selected. For example, hand tools that will be operated with one hand while the other hand is needed to provide support should not require two hand operations. Or devices that have to be operated in locations removed from outlets will have built-in power supplies. Or storage containers will not become obstructions, blocking physical or visual access to other equipment.

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Chapter 5
HUMAN FACTORS RESOURCES
Getting the Help You Need

This chapter includes two sections presenting considerations relevant to planning and staffing a continuing human factors program. Section 5.1 addresses planning considerations, including program needs for communications and coordination with personnel representing various occupations or disciplines. Section 5.2 suggests ways that managers can identify people who are well qualified to conduct specific human factors efforts.

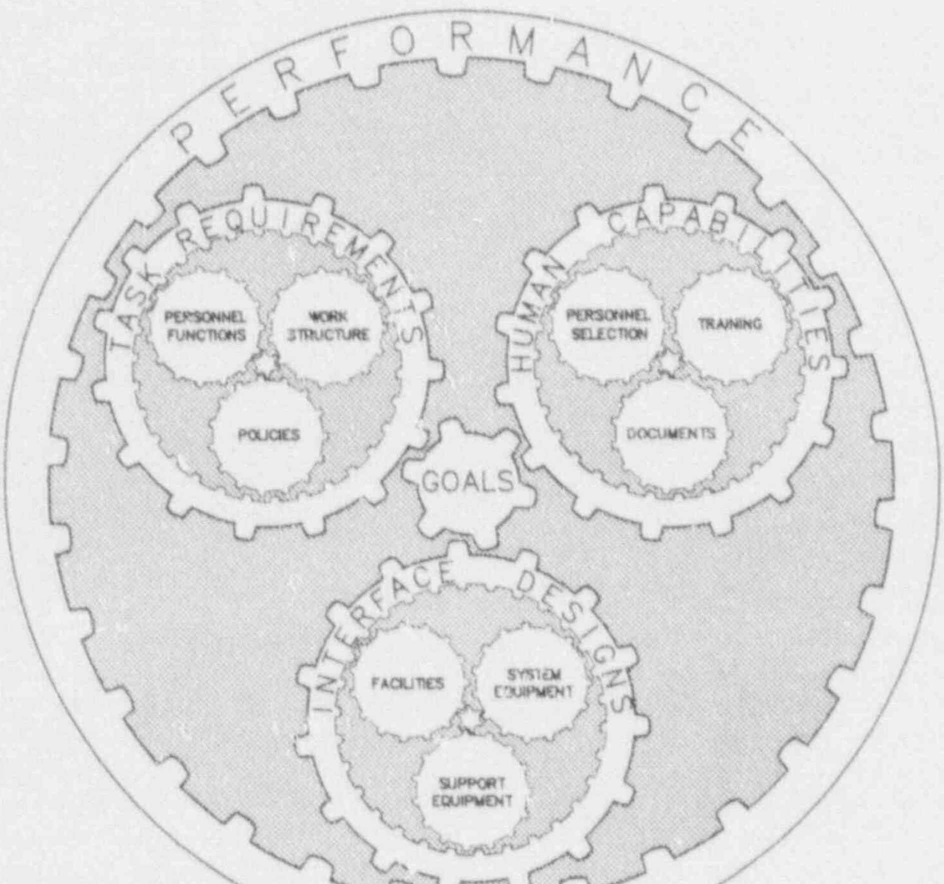

Exhibit 5-1. To help achieve plant goals, an effective human factors program systematically addresses all the interrelated factors that shape personnel performance.

Section 5.1
Decisions about Program Planning

This section addresses the following questions:

What progressive decisions can managers make about planning human factors efforts?

Are there good procedural precedents for planning a continuing human factors program?

What most influences the success of a utility's human factors program?

What scope of human factors program is appropriate?

From what organizational position is a human factors program best conducted?

When should human factors efforts be initiated?

How are human factors recommendations generally received?

Where can managers get help in developing a human factors program plan?

What progressive decisions can managers make about human factors efforts?

Decisions that provide for continuing, systematic application of human factors concepts and principles rather than sporadic, piecemeal efforts.

A utility's approach to planning human factors efforts differs according to what levels in the organization are convinced of the value of human factors engineering. If top management recognizes the benefits to be gained through a systematic goal-oriented program, other managers find it easier to reflect concern for human factors in the choices they make. Managers throughout the organization may contribute to planning a comprehensive program based on near- and long-term goals and changes that are already scheduled or that they envision.

Even if top management hasn't given its attention and support to a continuing human factors program, other managers can exert a positive influence. For example, equipment changes generally call for changes in the tasks performed by operators and technicians. The relatively small investment involved in representing a human factors viewpoint on the redesign team can help avoid costly retrofits later as well as oversights (e.g., lack of corresponding change to training and documents) that degrade personnel performance.

Are there good procedural precedents for planning a human factors program?

A few pioneering efforts have been made within the nuclear utility industry, but there isn't yet a consensus within the industry regarding the breadth and depth of human factors applications needed to help achieve plant performance improvement goals.

Prior to 1975, members of both the nuclear utility industry and the human factors community had little interest in programmatic human factors applications to plant designs or operations, with the exception of some isolated instances. In 1975, the first swell of interest in human factors arose with the publication of a highly visible NRC sponsored study, suggesting that serious consequences were more likely to result from human error in plant operations than from equipment failures.[1] About the same time, EPRI sponsored a human factors engineering review of five control rooms, photodocumenting specific error-prone designs.[2]

Soon after, a larger wave of interest in human factors arose in the wake of the Three Mile Island incident, as depicted in Exhibit 5-2. No calm, steady swell, it brought a spray of new regulations and stirred spirited dialogue among utility managers, owners' groups, NRC representatives, as well as the human factors community. When committees investigating the incident raised the notion that human factors had been ignored in plant developments,[3] many managers felt that they were collectively taking a bum rap. "We've always been concerned about the performance of people in the plant," they protested, "we just didn't call it human factors." This remark rang of truth, but also testified to a lack of awareness about the contributions the human factors profession can make when managers grapple with issues related to the performance of people.

Today, utility managers are much more familiar with human factors applications. Across the industry, control room designs have been reviewed and enhanced. Operator training has been transfigured, and emergency operating procedures are being revised. Organizations like EPRI and INPO have bolstered the industry's ability to address human factors problems, and professional groups like the American Nuclear Society and IEEE have sponsored meetings to promote exchange of information about human factors improvements. But, perhaps more importantly, members of the human factors community have become more acquainted with problems that are unique to the nuclear utility industry. While utility managers and human factors professionals alike still have a great deal to learn, amazing progress has been made in a very short time.

Yet it still remains for each utility to independently decide how it's going to use human factors resources to achieve plant performance improvements. Managers should consider taking the initiative by using qualified consultants or staff to help them plan a goal-oriented human factors program and determine how the program will be implemented.

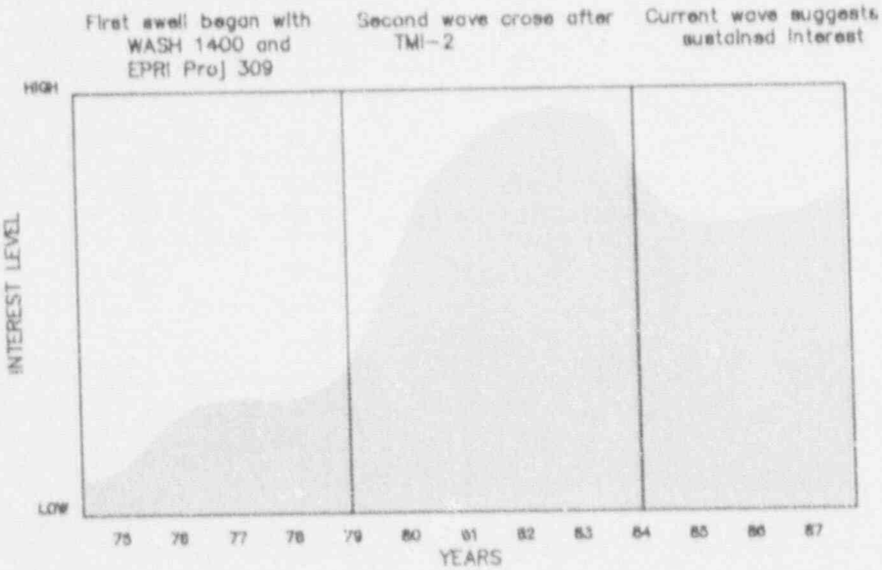

Exhibit 5-2. The industry's current interest in human factors has been likened to a "third wave" of progress.

What most influences the success of a utility's human factors program?

An unequivocal commitment on the part of its management and effective teamwork among its personnel.

Management commitment is reflected in allocating funds to formulate, communicate, and implement a program plan as well as in stating policies like:

- requiring human factors engineering representation on redesign teams at the outset of efforts,
- routinely requiring human factors review and sign-off before design changes are approved and implemented, and
- having an open door and the ability to resolve conflicts in perspective and produce cost-effective solutions to human factors related problems.

Effective teamwork involving human factors engineering is best accomplished within the context of multidisciplinary redesign teams. Other disciplines needed on redesign teams are those with the perspectives required to help achieve a balanced approach to solving problems. Besides the operators and technicians who perform equipment related tasks, the list typically includes a lead supervisor, design engineers, computer programmers, safety engineers, quality assurance inspectors, health/physics specialists, personnel administrators, training specialists, and document design specialists.

Most professionals employed by a utility find their expertise dovetails with concepts and principles represented in the human factors knowledge base. Despite differences in focus, they're likely to consider human factors applications consistent with their objectives and working methods and to welcome the support an active human factors program lends to their efforts.

What scope of human factors program is appropriate?

That depends on both near- and far-term plant performance goals.

The scope and objectives of the human factors program should be stated in terms of plant goals. Statements like "a 50% reduction of technician errors in surveillance testing" are better than statements like "redesign of maintenance procedures." That is, the latter assumes that even if a problem has multiple facets, only one partial solution should be attempted.

Since personnel performance is shaped by interrelated factors, effectively making even one change often means making corresponding changes to other aspects of the performance situation, as shown in Exhibit 5-3. Lack of an integrated approach to human factors improvements makes it hard for management to evaluate results and causes a disproportionate reduction in the benefits realized from investments made.

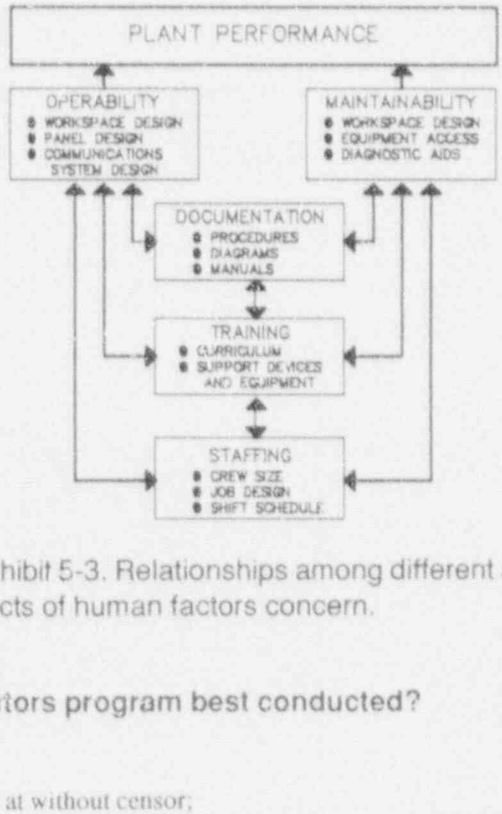

Exhibit 5-3. Relationships among different aspects of human factors concern.

From what organizational position is a human factors program best conducted?

From a position that permits:

- all factors potentially affecting performance to be looked at without censor;
- contact with all levels of station or plant management;
- the coordination needed to generate and foster acceptance of human factors recommendations; and
- freedom to aggressively promote improvements.

Responsibilities for managing human factors efforts are best located in a staff position that provides for easy access to managers of operations, maintenance, engineering, personnel administration, and training, as shown in Exhibit 5-4.

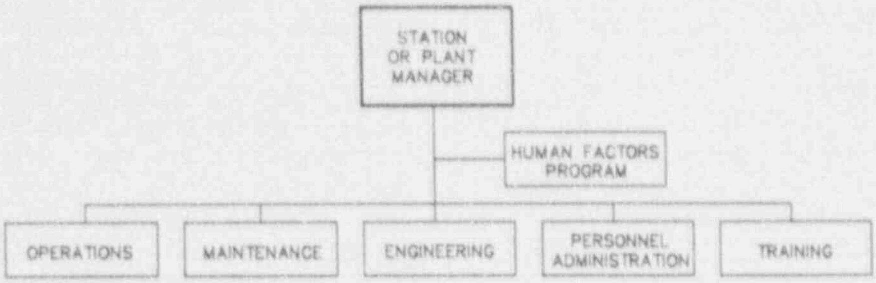

Exhibit 5-4. To facilitate required communications and coordination, responsibilities for managing a human factors program are best located in a staff position.

When should human factors efforts be initiated?

Whenever plant designs and programs are being evaluated for potential improvements.

As plans are conceptualized and pursued through a series of revision cycles, the cost of overcoming constraints imposed by early decisions neglecting human factors reduces freedom to consider alternatives, as shown in Exhibit 5-5. By the time managers are required to approve a major program change or authorize the cost of implementing a new interface design, human factors enhancements may add substantially to the costs already incurred. Final "go or no-go" decisions compromise a lot of important values in between, values that should be represented in trade-off decisions throughout an improvement effort.

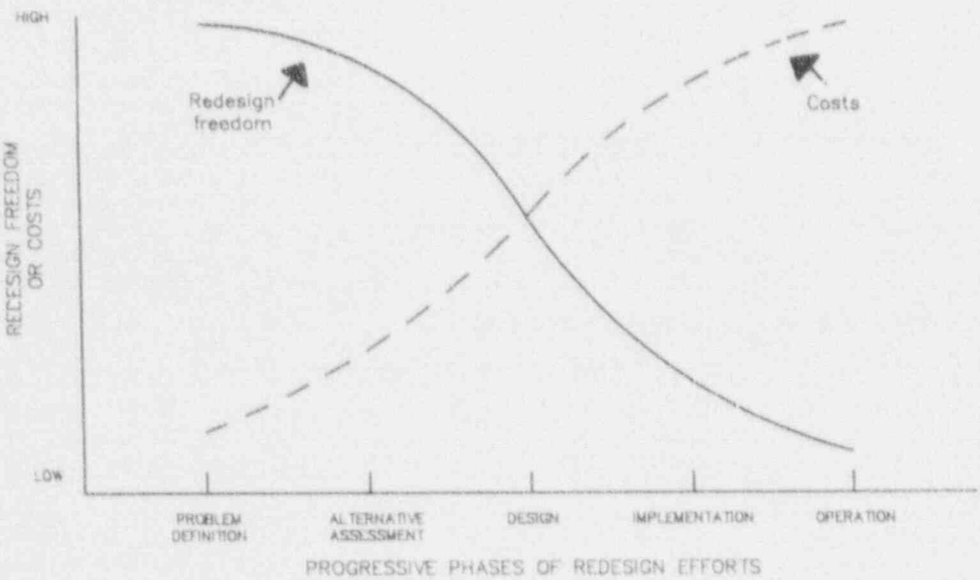

Exhibit 5-5. Relationships between design freedom and costs.

How are human factors recommendations generally received?

With a mixture of reservation, negotiation, and appreciation, depending on the perspective of the recipient.

Reservation is commonplace among those managers and design engineers who're more concerned about costs incurred this year or next than total cost/benefits over the far term. In many cases, human factors applications require "expenditure today for the benefits of tomorrow."

Some negotiation is usually involved in exchanges between engineering and human factors professionals. The human factors engineer has to be a user advocate, challenging design solutions while helping to bring balance to the design perspective. Some engineers who have been involved in producing design solutions resent have their designs challenged. But, designs hammered out through an interprofessionally challenged team may come closer to excellence than those offered by complaisant peers because, as the saying goes, "there is little progress where there is no friction." When too much heat is produced by friction caused by different perspectives, it is best dissipated by the lead manager who is ultimately responsible for the success of the redesign effort in question.

Operators and technicians are more likely to greet evidence of human factors engineering with appreciation. They are often gratified that management is doing something to eliminate difficult or annoying aspects of their jobs.

Where can managers get help in developing a human factors program plan?

From human factors professionals with broad experience in system developments as well as familiarity with innovative solutions applied to the nuclear power industry.

If your utility already employs full-time human factors engineers, they can help develop a plan, schedule, and budget that accounts for all resources needed to implement programmatic human factors efforts. They can help determine whether existing personnel can provide the time and expertise needed or what kind of additional professional help is called for. You may have to recruit specialists or contract with a consulting firm to acquire certain human factors products and services. Or, if you don't have human factors engineers already on board at your utility, you may want to first engage consultants to help you develop a workable plan for a human factors program.

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Decisions about Human Factors Staffing

This section includes the following questions:

What progressive decisions can managers make about human factors staffing?

What are people who professionally practice human factors called?

Are qualified human factors engineers licensed or certified in some way?

What educational credentials should you look for when selecting human factors engineers?

What's the relation between complexity of human factors applications and recommended years of education and experience?

Besides education and experience, are there other indicators of professional competence for human factors engineers?

How does understanding the beginnings of the human factors discipline lead to an appreciation of practitioner qualifications?

Are all human factors engineers also psychologists?

How might you go about obtaining the services of human factors consultants?

What progressive decisions can managers make about human factors staffing?

Decisions to obtain personnel with the qualifications needed to address specific human factors applications.

Some managers may be tempted to use available resources, such as design engineers or people with operational experience, to effect human factors applications. The thought may be that the familiarity of such personnel with plant operations, supplemented by information learned at seminars and workshops, is sufficient to fully reap the benefits of human factors applications in plant improvements.

A little knowledge of human factors can help bring anyone to an awareness of basic human factors principles and concerns. Some simple applications can be effectively performed by people with limited qualifications. But complex human factors applications call for efforts where advanced, specialized education is needed along with experience in system developments.

For complex applications, you wouldn't want to rely only on personnel who have had a limited exposure to and experience using the human factors knowledge base. For example, you shouldn't expect someone who has attended a human factors workshop to be able to deal effectively with complex human factors issues any more than you would expect a technician who has attended a short course on control theory to begin making changes in plant safety systems.

It's important that the qualifications of those who address human factors at your plant be suited to the nature and complexity of the issues involved. For some applications, you'll need people who professionally practice human factors engineering.

What are people who professionally practice human factors called?

Usually, they are called human factors engineers, but sometimes they are called human factors specialists or ergonomicists.

People who practice human factors on a broad front are called human factors engineers or simply human engineers. But, human factors is a discipline that addresses diverse and heterogenous concerns. No one person could know all of the facets related to specialized areas within human factors.

Professionals who practice human factors engineering within specialized areas are called human factors specialists. Most human factors specialists have a preponderance of experience in a single area of application — like surveying and assessing environmental conditions or addressing computer interface designs. Specialists may devote a lifetime to advancing the state of the art in a single area of human factors.

Sometimes human factors engineers are also called ergonomicists. Ergonomics, literally meaning the study of work, is roughly synonymous with human factors and implies no particular emphasis.

Are qualified human factors engineers licensed or certified in some way?

No, not currently.

Recently, the need for licensing or certification standards and procedures has raised increasing concern within the profession. The Human Factors Society, founded in 1957 to "promote the discovery, exchange, and application of knowledge concerning the relationship of people to their machines and their environment," now includes more than 4,000 members. But the only requirements for membership are that an applicant have a Bachelors degree (experience in the field can be substituted), three years minimum experience in human factors work or related areas, be sponsored or recommended by at least two existing members, and pay a membership fee.[1]

In time, consensus on certification standards will probably emerge. In the meantime, some general guidance can be offered in selecting qualified human factors professionals.

What educational credentials should you look for when selecting human factors engineers?

Those related to the kinds of applications you'll be looking for.

An understanding of the principles and concepts from various fields within psychology is needed to make informed contributions to decisions related to different human factors applications. The fields of psychology that contribute the most to selected areas of human factors applications are shown in Exhibit 5-6. While education in engineering psychology provides a basis for a variety of applications, studies in other fields may also be needed.

But completion of an educational experience or even graduation from a recognized program of advanced education is only one indicator of qualifications to practice human factors engineering. As in other screening situations, you have to consider academic credentials in combination with other experience. This is particularly true in the case of individuals who lack impressive academic credentials, but have more than compensated for this in their professional achievements as members of research and development teams.

What's the relation between complexity of human factors applications and recommended years of education and experience?

As the complexity of human factors applications increase, so should the number of years spent obtaining an education and applying it.

For simple applications, such as applying checklists to existing designs, having an advanced education is not needed and it is probably detrimental to effective performance. However, as the complexity of issues addressed increases, there is a need for specialized education. Years of experience can substitute for years of

SELECTED AREAS OF HUMAN FACTORS APPLICATIONS	FIELDS OF PSYCHOLOGY PROVIDING PRINCIPLES AND CONCEPTS *
TASK REQUIREMENTS	
Function Allocation	
Identifying troublesome tasks	METHODS
Recommending function reallocations	ENGINEERING
Providing human capability information	EXPERIMENTAL
Work Structure	
Organizing job positions	INDUSTRIAL
Designing jobs	INDUSTRIAL
Policies	
Governing planning, coordination, and supervision	INDUSTRIAL
Establishing work schedules	PHYSIOLOGICAL
Guiding performance rewards	INDUSTRIAL
HUMAN CAPABILITIES	
Personnel Selection	
Identifying needed capabilities	ENGINEERING
Recommending tests	INDIVIDUAL DIFFERENCES
Training	
Identifying training needs	ENGINEERING
Recommending instructional techniques	EDUCATIONAL
Recommending training device features	ENGINEERING
Suggesting training validation measures	ENGINEERING
Documents	
Specifying use conditions	METHODS
Defining relevant content	ENGINEERING
Recommending conventions	EDUCATIONAL
Designing evaluation trials	METHODS
INTERFACE DESIGN	
Facilities	
Identifying facility design discrepancies	INDUSTRIAL
Surveying environmental conditions	ENVIRONMENTAL
Providing design solutions	ENGINEERING
System Equipment	
Identifying equipment design discrepancies	METHODS
Recommending enhancements	ENGINEERING
Recommending computer–generated display designs	ENGINEERING
Designing evaluation trials	METHODS
Support Equipment	
Assessing material handling and other tool designs	ENVIRONMENTAL
Evaluating communications	PHYSIOLOGICAL
Contributing to robotic and protective gear selection	ENGINEERING

* DEFINITION OF PSYCHOLOGICAL FIELDS CONTRIBUTING TO HUMAN FACTORS APPLICATIONS [2]

EXPERIMENTAL –– STUDIES HOW PEOPLE REACT TO STIMULI, PERCEIVE, LEARN AND REMEMBER, AND ARE MOTIVATED.
PHYSIOLOGICAL –– STUDIES BIOLOGICAL PROCESSES AND THE BIOMECHANICS OF THE BODY.
INDIVIDUAL DIFFERENCES –– STUDIES WAYS OF CLASSIFYING AND MEASURING DIFFERENCES AMONG PEOPLE.
METHODS –– STUDIES WAYS OF COLLECTING AND ANALYZING BEHAVIORAL DATA.
EDUCATIONAL –– SPECIALIZES IN APPLICATIONS TO TRAINING AND EDUCATION.
INDUSTRIAL –– SPECIALIZES IN WORK–RELATED, ORGANIZATIONAL, AND MANAGEMENT ISSUES.
ENVIRONMENTAL –– SPECIALIZES IN PROBLEMS OF NOISE, LIGHTING, AND CLIMATE.
ENGINEERING –– SPECIALIZES IN ENGINEERING PSYCHOLOGICAL FACTORS AFFECTING PERFORMANCE.

Exhibit 5-6. The psychological fields that should be reflected in educational credentials for human factors engineers providing various applications.

education in some cases, but usually more years of experience are needed, particularly where complex issues are at stake, as shown in Exhibit 5-7. For some very complex applications, such as formulating plans and assessing complicated tradeoffs, specialized education is usually needed.

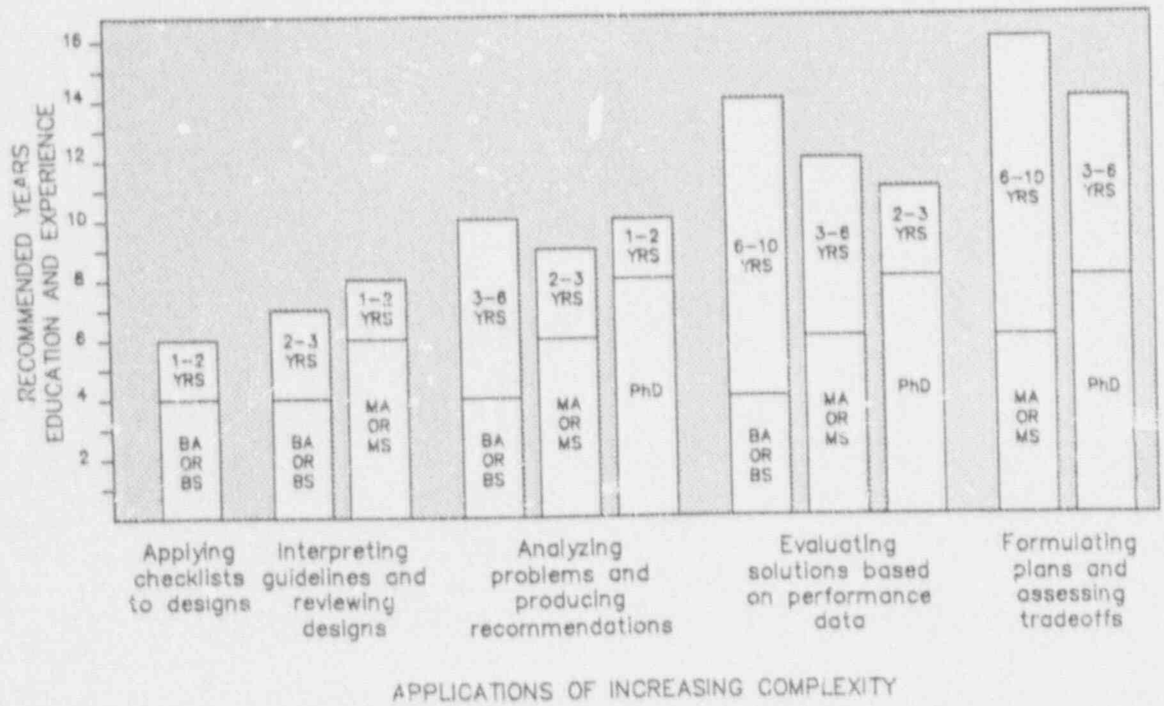

Exhibit 5-7. The recommended years of education and experience for varying levels of human factors applications.

Besides education and experience, are there other indicators of professional competence for human factors engineers?

Yes, membership in professional societies and contributions to technical publications.

Membership in professional societies and publication in journals reflects an interest in the discipline. While society membership alone doesn't ensure current awareness of recent advances in the discipline, it does reflect a professional interest in and support of the discipline.

While many practicing human factors engineers have little opportunity to publish in professional journals, those that do have demonstrated an ability to contribute to the human factors knowledge base. This may be important if you are looking for innovative applications.

How does understanding the beginnings of the human factors discipline lead to an appreciation of practitioner qualifications?

Because the human factors discipline is an offspring of psychology and some applications depend on a knowledge of different fields of psychology.

The human factors discipline became established during World War II. Aviation engineers were faced with challenges of unprecedented criticality. Devoting their attention to dealing with equipment factors in innovative aircraft design, they assumed crews could readily be trained to operate and maintain the technologically sophisticated planes they developed. But as bombs and bullets missed their marks and new planes crashed or sat useless on the sidelines, 20-20 hindsight pinned a series of costly failures on neglect of "the human factor" in system development.

Psychologists had been involved in personnel selection and training of military personnel for at least 20 years before the war. But universal draft put within the ranks more psychologists than any previous military organization had known, or known what to do with. In the wisdom of desperation, military leaders asked some psychologists to look at aircrew performance problems and come up with useful recommendations. Thus began a collaboration between psychologists and engineers that helped make our aircraft safer, more available, and more effective in their missions. Successful resolution of similar human performance problems in all branches of the military gave rise to the human factors discipline.

So, the human factors discipline was started by applying the principles and concepts of psychology to solving problems experienced with military aircraft. While the discipline has expanded its knowledge base beyond that of psychology, people who practice human factors engineering should be aware of the fact that certain psychological principles and concepts are needed to contribute to solving personnel related problems.

Are all human factors engineers also psychologists?

No.

Today, over fifty colleges and universities offer advanced degrees in human factors. About half of these locate human factors within departments of industrial engineering. Only 18 locate it within the department of psychology. Within the Human Factors Society, the major professional organization devoted to advancing the discipline, a little more than half the members have degrees in psychology. About 20% have engineering degrees. The remaining members have degrees in other academic specialties, including life sciences, business administration, education, and computer sciences.

How might you go about obtaining the services of human factors consultants?

By asking reputable firms to describe how they can help you solve specific problems along with the credentials of the people who will be applied.

Some firms that offer human factors consulting services buy advertising space in *Nuclear News* and other publications that are popular in the industry. You may be familiar with the names of some of these firms, but don't hesitate to look for others or get more information about any human factors firm. Human factors, as in most disciplines, unhappily has a few opportunists and fly-by-nighters who are interested in a quick buck. Money spent on their employment will not only be squandered but could actually be harmful.

You may want to write or call the local chapter of the Human Factors Society for a list of firms in your area with a human factors capability. You may also ask for evaluations of the professional qualifications of the firm's staff. In addition, you will definitely want to obtain a list of nuclear power plant customers for whom the human factors firm has worked. From these customers, you should obtain valuative comments as to the professionalism, cost, timeliness, and usefulness of the consultant's inputs.

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GLOSSARY

Abilities are traits inherent at birth that establish limitations in what people can do.

Ability tests provide both psychological and physiological measures of inherent traits including, for example, tests of hearing, perception, memory, and motor abilities as well as tolerances to environmental conditions like dust, chemicals, and heat.

Achievement tests assess various knowledge and skills a person already possesses.

Advanced control complexes typically offer not only generic process control programs and formats for computer-integrated displays but consoles designed to accommodate a number of display screens.

Aptitude tests predict success in scholastic or differing vocational endeavors.

Aptitudes are innate potentials for developing abilities into capabilities through specific learning experiences.

Attitude surveys provide information about personal values, beliefs, and preferences.

Attitudes are related to innate personality variables, but they're also shaped by experience.

Biological rhythms are cyclical changes in physiological measures that occur over time.

Branching provides instruction at different levels of detail to accommodate ranges of aptitudes and capabilities among the personnel being trained.

Centralized organizations have many vertical levels but few horizontal branches.

Circadian rhythms are cyclical changes in physiological measures that occur over a 24-hour period.

Comfort zone is an envelope of climatic conditions that most people find comfortable, created by a combination of different temperatures and humidities.

Computer generated displays provide representations of sensor signals that have been processed by a computer and then displayed on a screen.

Controlled vocabulary is a set of authorized terms that designers and other personnel alike agree to use in preference to any synonyms.

Critical incident techniques require plant personnel to relate unusual incidents, and in some applications the incidents are restricted to those that could have led to an accident or mishap had personnel not been on their toes.

Decentralized organizations have few vertical levels and many horizontal branches.

Deterministic operations are operations that can be completely described by physical laws expressed in mathematical formulae, from a set of rules expressed in the form of algorithms, or from a set of heuristic procedures expressed in the form of sequential steps.

Display/control relationships the relations among displays presenting information and the controls used to change the information.

Diurnal rhythms are cyclical changes in physiological measures that occur daily.

Embedded training provides practice opportunities during normal operations with plant equipment.

Equipment performance monitoring devices detect changes in temperatures, vibration, noise, magnetism, or a variety of other signatures of incipient malfunctions.

Ergonomics, literally meaning the study of work, is roughly synonymous with human factors and implies no particular emphasis.

Facility designs determine how well personnel can locate, travel to, reach, and move objects; can see or hear information; and are protected from environmental stresses and hazards.

Fidelity of simulation refers to the degree of realism reflected in representations of on the job stimuli and dynamic responses in a training device.

Fifth-to-ninety-fifth percentile rule means that an acceptable design is one that well accommodates 90% of personnel (both males and females), but people who're below the fifth percentile or above the ninety-fifth percentile on relevant measurements have to "try harder" or, for critical task dependent capabilities, be screened out.

Functional flow block diagram is a way of depicting the specific functions and their interrelationships needed to accomplish a broad function.

Group paced instruction is geared to the slower learners in a group.

Human capabilities are the sum of heredity and experience and establish what personnel are able to do.

Human error is simply a deviation in personnel performance from a specified standard.

Human factors are all the variables in a work situation that interactively shape personnel performance.

Human factors engineering is the systematic application of principles and criteria derived from what's known about human performance to improve operations involving people.

Human factors engineers are people who practice human factors on a broad front.

Human factors specialists are professionals who practice human factors within specialized areas.

Hybrid system a combination of computer generated displays and various hardwired instruments.

Initiating cues indicate a discrepancy between an existing condition and a system or organizational functional requirement.

Interface designs reflect not only display and control features needed to exchange information between personnel and equipment, but other conditions affecting such exchanges.

Interview methods include unstructured, structured, and critical incident techniques.

Job ladders establish a recognized basis for career advancement.

Job performance standards are stated measures of performance where specific values have to be achieved to satisfy functional or organizational requirements.

Job performance aid originally suggested a little book with detailed information and illustrations intended to support performance of certain tasks or task steps, but the term has come to encompass not only procedures, but instruction sheets, troubleshooting guides, maintenance dependency charts, checklists, conversion tables, and even computer-driven expert systems that interactively present information to help guide task performance.

Knowledge is information retained in memory and used to perform tasks.

Labeling usually involves identifying system, subsystem, and train or loop hierarchies in display/control labels, with associated coding applied to facilitate easy recognition.

Man-machine interface is any point where energies are received or transmitted by personnel.

Negative transfer of learning has occurred when job performance is actually worse than if no training had been provided.

Normal distributions, plotted out, are bell-shaped and the extremes represent the number of people who're far above or below average in a specific measure.

Organizational functions dictate what has to be done to plan, coordinate, and supervise system equipment operations as well as to protect plant security and personnel health and safety.

Overlearning refers to repeated exposures to situations already mastered, to help ensure retention of critical or infrequently used knowledge and skills.

Performance based training refers to the procedures used during training program development, where training needs are identified by defining differences between the capabilities needed to satisfy job task requirements and the qualifications of selected personnel.

Personality tests provide a basis for predicting behavioral patterns.

Plant policies define various aspects of how work is managed, scheduled, and rewarded.

Plant safety includes not only eliminating potentials for release of radioactivity to the environment, but reducing the radiation exposure of personnel and the likelihood of their suffering injury or of equipment being needlessly damaged.

Positive transfer of learning has occurred when training quickly produces highly proficient performance on the job.

Post-tests involve testing after instruction.

Pre-tests involve testing before instruction.

Psychological fidelity refers to how realistic a training device seems to personnel, as opposed to how slavishly it duplicates inconsequential characteristics of actual equipment.

Questionnaires typically contain a set of questions and a range of answers for each.

Readability indexes are a means of quickly identifying if the text of a document is likely to exceed the reading capabilities of personnel.

Robotic devices perform operations that are similar to tasks performed by personnel.

Scheduled work breaks are breaks where a person is periodically relieved from duties

Self paced instruction is geared to each individual's learning rate.

Simple task analysis involves extracting information from plant procedures about the sequence of personnel interactions with system equipment.

Skills are capabilities that can only be acquired through practice.
Pacing the rate of presenting instruction.

Structured interviews require all plant personnel to respond to a predetermined set of questions aimed at isolating specific problem areas (e.g., inefficiencies in the location of workshops, tool rooms, warehouses; inadequate lighting; access problems) that could degrade personnel performance.

Support equipment is a catch all term for any device that increases what people are able to do safely and comfortably.

System functions dictate what and how well something has to be done to safely operate system equipment.

Talk-through a technique for identifying tasks by having experienced personnel describe what they are doing, and why, as they pretend to perform each step while interacting with plant equipment.

Task analysis is a combination of techniques used to describe what personnel have to do so meaningful conclusions can be drawn about how performance can be improved.

Task requirements are the prescribed standards applied to activities personnel must perform.

Tasks are segments of work assigned to personnel and are determined by a combination of system and organizational functions thought to be needed to safely operate a plant.

Terminating cues indicate that a failure to satisfy a system or organizational functional requirement has been corrected.

Transfer of learning is the transfer of knowledge, skills, and attitudes learned in training to performance on the job.

Unstructured interviews require plant personnel to respond to general questions (e.g., about the adequacy of training, documents, facilities) with the interviewer asking more specific questions based on the answers received.

Walk-through a technique for identifying tasks by having experienced personnel pretend to perform each step while interacting with plant equipment.

Work structuring entails identifying task requirements and then determining how duties could be distributed across jobs.

INDEX

Abilities, defined, 42
Ability tests, defined, 42
Achievement tests, defined, 42
Advanced control complexes, 63
Alarm and annunciator design improvements, 71
Angle of inclination coding, 72
Aptitude tests, defined, 42
Aptitudes, defined, 42
Attention getting value of signs and placards, 61
Attitude surveys, defined, 42
Attitudes, defined, 42
Automated testing, 43
Availability, see Plant availability
Benefits of human factors engineering, 16
Biological rhythms, defined, 37
Biomechanical information, 75
Body dimensions, 61
Branching, defined, 48
Centralized organizations, 30
Circadian rhythms, 37
Climatic measures, 65
Coding of the angle of inclination in computer generated displays, 72
Color coding in design enhancements, 69
Color coding of hazardous equipment, 69
Comfort zone, 65
Communications design, 76
Computer generated displays, defined, 70
Concept of an average person, 41
Conceptual framework,
  costs and lost revenues due to personnel performance, 3
  decisions about human capabilities, 5
  decisions about interface designs, 6
  decisions about task requirements, 5
  human capabilities defined, 5
  human factors defined, 2
  human factors under management control, 8
  interface defined, 6
  plant performance goals, 2
  task requirements defined, 3
Console configurations, 63
Controlled vocabulary, 54
Cost and lost revenues passed on to consumers, 3
Critical incident technique, defined 11
  applied to policy decisions, 38
  applied to document decisionss, 53
Decentralized organizations, 30
Design enhancement, 68
Deterministic operations, 26
Display page formats, 71
Display page limitations, 71
Display/control integration, 70
Display/control relationships, 68
Diurnal rhythms, 37
Documents,
  distinction between job performance aids and other plant documents, 53
  innovations, 56
  progressive decisions about, 52
  reasons for improving, 52
  role of human factors engineering in, 58
  task aspects suggesting a need for document support, 54
  use of a controlled vocabulary, 54
  use of a readability index, 54
  use of graphics to support text, 55
  use of guidelines and conventions, 55
  validation of, 56
Embedded training, defined, 27
Equipment performance monitoring, 72
Ergonomicists, see Human factors engineers
Ergonomics, defined, 86
Evaluation of computer generated displays, 72
Expectations about display/control relations, 68
Eye-hand movement patterns, 68
Facility designs,
  affect of signs and placards on performance, 61
  affects of an advanced control complex on, 63
  environmental conditions of human factors engineering concern, 64
  impact of conventional and advanced displays on lighting requirements, 64
  progressive decisions about, 60
  role of human factors engineering in, 65
  techniques used for layout assessment, 62
  use of data about body dimensions in, 61
Fidelity of simulation, defined, 49
  related to transfer of learning and investment costs, 50
Fifth to ninety-fifth percentile rule, defined, 62
Fixed shifts, 37
Frozen water vest, 16
Function allocation, see Personnel functions
Functional flow block diagram, 25
Graphic display pages, 71
Graphics, 56
Graphs, when to use in documents, 56
Group-paced training, defined, 47
Hearing sensitivity, 76
Heat stress management guidelines, 17
Hierarchical labeling, 69
Hostile environments, 65
Human capabilities, defined, 5
  decisions about documents, 52
  decisions about personnel selection, 40
  decisions about training, 45
Human engineers, see Human factors engineers
Human error, defined, 10
  and costs and lost revenues, 3
  percentage of plant events caused by, 9
  root causes of, 10

Human factors applications, objectives, 9
pay offs resulting from, 3
Human factors engineering objectives, methods, and benefits,
aspects of tasks to be analyzed, 15
benefits of human factors engineering applications, 16
human error and plant events, 9
human factors engineering defined, 9
human factors engineering methods, 10
human factors surveys discussed, 12
questionnaires and interviews discussed, 11
reasons for human error, 10
sources of human factors engineering information, 10
task analysis discussed, 13
task analysis techniques identified, [illegible]
test and evaluation trial uses, 15
Human factors engineering, defined, 9
a conceptual framework for, 2
misconceptions about, 18
objectives, methods, and benefits of, 9
Human factors engineers, defined, 85
Human factors principles, related to work structure, 32
Human factors program planning,
influences on program success, 81
procedural precedents, 80
program position within the utility, 82
program scope, 82
progressive decisions about, 80
reactions to human factors recommendations, 83
timing of human factors efforts, 83
where help can be found, 84
Human Factors Resources,
decisions about program planning, 80
decisions about staffing, 85
Human Factors Society, 86
Human factors survey methods, listed, 12
applied to support equipment designs, 77
applied to the environment, 64
Human factors, defined, 2
under management control, 8
Hybrid system, defined, 70
Initiating cue, defined, 3
Interface designs, defined, 6
decisions about facilities, 60
decisions about support equipment, 74
decisions about system equipment, 66
Interview methods, defined, 11
Job dissatisfaction, 33
Job performance aids, defined, 54
Job performance standards, defined, 33
derivation of, 34
Job satisfaction, 33
Job standards, see Job performance standards
Knowledge, defined, 47
Labeling and coding techniques, 68
Licensing or certification of human factors engineers, 86
Lighting design considerations, 64
Lighting requirements, 64
Line drawings, when to use in documents, 56
Lines of demarcation, 69
Link diagram, defined, 62
uses of in facility design, 63
Logic tree diagrams, when to use in documents, 56
Machine-readable documents, 56
Man-machine interface see also Interface designs
Man-machine interface, defined, 6
Misconceptions about human factors engineering,
addresses apparent trifles, 18
can find information in a handbook or guide, 20
concerned mainly with knobs and dials, 19
nothing more than common sense, 18
provides answers to any question about people, 21
Mockups, criteria for using, 49
Negative transfer of learning, defined, 49
Normal distribution, defined, 41
Operational sequence diagram, 68
Organizational design, see Work structure
Organizational functions, defined, 3
Organizational policies, see Plant policies
Overlearning, defined, 50
Overtime, 36
Pacing, defined, 47
Paint, label, and tape techniques, 68
Panel design assessment techniques, 68
Performance based selection program, defined, 40
Performance based training program, defined, 45
Performance monitoring of equipment, 72
Performance standards, see Job performance standards
Personality tests, defined, 42
Personnel functions,
information needed to consider reallocating, 25
pitfalls from reallocating, 26
progressive decisions about, 24
reasons for reallocating, 24
Personnel selection,
concept of an average person, 41
distinctions among abilities, aptitudes, attitudes, and capabilities, 42
information given to personnel administrators, 41
information needed to get cost-effective strategies, 41
progressive decisions about, 40
reasons for changing existing procedures, 40
role of human factors engineering in, 43
testing innovations, 43
variety of useful screening instruments, 42
Photographs, when to use in documents, 56
Plant availability, 3
Plant goals, and level of investment needed, 3
Plant performance goals, identified, 2
Plant policies, defined, 35
progressive decisions about, 35
reasons for changing, 35
related to information management, 36
related to planning and coordination, 36
related to rewards and discipline, 37
related to work breaks, 37

related to work scheduling, 36
role of human factors engineering in, 38
Plant productivity, 3
Plant safety, 2
Positive transfer of learning, defined, 49
Protective clothing, 76
Psychological fidelity of simulation, defined, 51
Questionnaires and Interviews,
and work structure decisions, 30
related to policy decisions, 78
uses of, 11
Questionnaires, defined, 11
Readability index, defined, 54
and comprehension, 55
Robotic devices, 77
Root causes of human error, 10
Rotating shifts, 37
Scheduled work breaks, 37
Schematic or mimic display pages, 71
Self-paced training, defined, 47
Shift rotation, 37
Signs and placards, 61
Size coding of labels in design enhancements, 69
Skill acquisition stages, 48
Skills, defined, 47
Social factors, related to shift rotation schedules, 37
Speaking ranges, 76
Staffing,
relation of education in psychology to the practice of human factors, 89
educational credentials, 86
licensing or certification of human factors engineers, 86
obtaining the services of consultants, 89
other indicators of professional competence, 88
progressive decisions about, 85
relation between complexity of the job and qualifications needed, 86
relation of the human factors discipline to psychology, 88
titles of human factors practitioners, 85
Stages of skill acquisition, 48
Structured interview, defined, 11
Support equipment, defined, 74
human factors information used in communications design, 76
impact of robotic devices on task requirements, 77
material handling device improvements, 76
progressive decisions about, 74
reasons for improving, 74
role of human factors engineering in, 77
uses of biomechanical information in, 75
Surveyor, 77
Surveys, see Human factors surveys
System equipment interfaces,
alarm and annunciator design improvements, 71
computer generated displays, 70
importance of display/control relationships, 68
innovations in, 72
labeling and coding techniques used for design enhancement, 68
panel design assessment techniques, 68
pitfalls associated with computer generated displays, 70
progressive decisions about, 66
reasons for improving, 66
role of human factors engineering in, 72
System functions, defined, 3
Tabular or trend display pages, 71
Talk-through, defined, 13
Task analysis defined, 13
Task analysis,
and work structure decisions, 30
aspects of tasks to be analyzed, 15
conduct of, 13
techniques used in, 15
Task requirements, defined, 3
decisions about personnel functions, 24
decisions about plant policies, 35
decisions about work structure, 29
Tasks, defined, 3
Terminating cue, defined, 3
Test and evaluation, 15
Timeline analysis, 31
Tools and protective clothing, 75
Training devices, criteria for using, 48
Training,
distinction between knowledge and skills, 47
instructional features affecting training costs, 47
overlearning, 50
performance based training compared to subject matter expert training, 46
progressive decisions about, 45
reasons for improving, 46
relation of human factors engineering to training technology, 46
role of human factors engineering in, 50
training device advantages, 48
transfer of learning, 49
Transfer of learning, defined, 49
Transfer of training, 49
Unstructured interview, defined, 11
Walk-through, defined, 13
Warning and caution placards, 61
Work breaks, 37
Work scheduling policies, 36
Work structure,
and human factors methods, 30
and job performance standards, 33
and job satisfaction, 33
and organizational design, 30
objectives of restructuring, 29
progressive decisions about, 29
reasons for restructuring, 30
related human factors principles, 32
role of human factors engineering in, 34
Zone surveillance, 77

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