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MANAGEMENT

Good Practice Guide
GPG-FM-027

Human Factors Engineering

March 1996

Department of Energy
Office of Field Management
Office of Project and Fixed Asset Management

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1. INTRODUCTION

1.1 Purpose

Human factors engineering (HFE) is the application of the knowledge of human capabilities and characteristics to the development of engineered equipment, facilities, and systems. By applying this knowledge, human performance, and therefore system performance, can be improved dramatically. Man/machine systems designed with the human as a key element are inherently safer and more reliable than those that are not. Over the years, more than a few accidents involving aircraft, military weapon systems, and nuclear power plants have been attributed to "human or operator error." What is typically not emphasized is that in many instances, causes of human error result from poorly designed human/equipment interfaces. It is the goal of HFE to ensure that the potential for this "design-induced" human error is minimized.

Accordingly, this guide describes a methodology for applying the principles and practices of human factors engineering to Department of Energy (DOE) engineering and construction projects. This is necessary to ensure that equipment and facility designs support safe and effective human performance.

1.2 Using This Guide

Most systems require substantial involvement by human operators and/or maintainers. Application of good HFE design criteria during system development is therefore vital for optimal system performance for operation and maintenance activities. Until recently, however, design of these human/equipment interfaces has been secondary to "pure hardware" design; that is, equipment and facilities have been designed without formal consideration of the implications for the operators and maintainers. A disciplined approach to HFE helps ensure that humans are considered integral system components, requiring careful consideration of how they will interact with their equipment. By following the methodology presented here, many potential deficiencies in human/equipment interfaces can be avoided, as can the costs consequences of field re-design and/or "human error" accidents.

The concepts and approaches in this guide can be applied, on a graded basis, to any DOE engineering or construction project. Obviously, the complexity and level of human interfaces in the system and the potential consequences of equipment failures will determine the degree to which formal HFE should be applied. Many DOE construction projects involve design of simple storage or office facilities for which additional HFE effort is not needed or cost-effective. Other projects, however, may consist of state-of-the-art research, development, or production facilities for which extensive HFE involvement is required during design and development.

As with other specialty engineering disciplines (reliability and maintainability, e.g.), the most critical and cost-effective point at which to begin the HFE effort is during the early phases of system concept development or facility design. Serious consideration of the human role in the system can result in early design decisions that will facilitate synthesis of a “user-friendly” system architecture. Likewise, a lack of commitment to HFE during concept development can lead to less than optimal human/equipment interfaces, with the potential for undesirable system performance.

This guide is primarily intended for Program and Project Managers and their staff members who oversee engineering projects involving considerable design effort. Because the Project Manager is ultimately responsible for technical aspects of the system as well as cost and schedules, he/she must be aware of the HFE role in system design. The Project Manager must be knowledgeable of the HFE effort and its integration with the overall project and the contributions a Human Factors Engineer can make to a design and construction project.

Members of the design team will also benefit considerably from this guide by gaining an appreciation for designs which consider the human as a key system component, necessary for safe and effective human interfaces. A knowledge of the HFE methodology and how it fits into overall system development will enhance the acceptance of HFE by the more traditional engineering disciplines.

2. PRINCIPLES AND PROCESSES

The HFE effort will provide the best results when integrated with the development of a system. Figure 1 shows the Life Cycle Model for a system. Mapped onto the Life Cycle Model is a set of HFE efforts that should be implemented. These efforts are developed in the following sections of this guide.

Key to a HFE effort is the repeated application of a simple HFE Model shown in Figure 2. The main elements of this model are:

Task Analysis; represents the development of the man-system interface needed. The man-system interface should result from the functional analysis and the assessment that man or automation can best accomplish the function.

Design; results in the implementation that will satisfy the needed interface.

Risk Assessment; establishes the detail and rigor needed in the design to satisfy the task.

Figure 1: Life Cycle Model

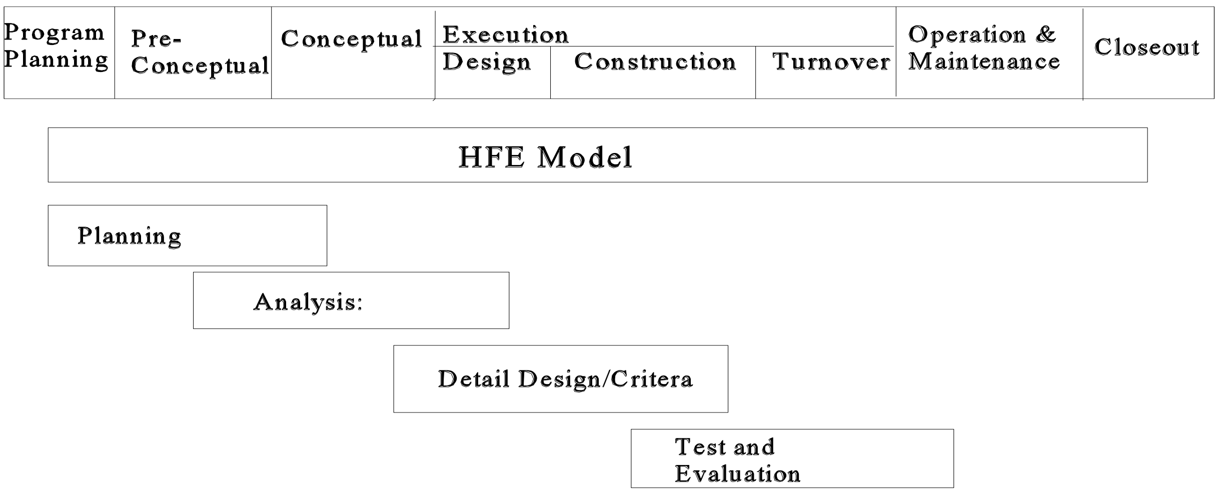
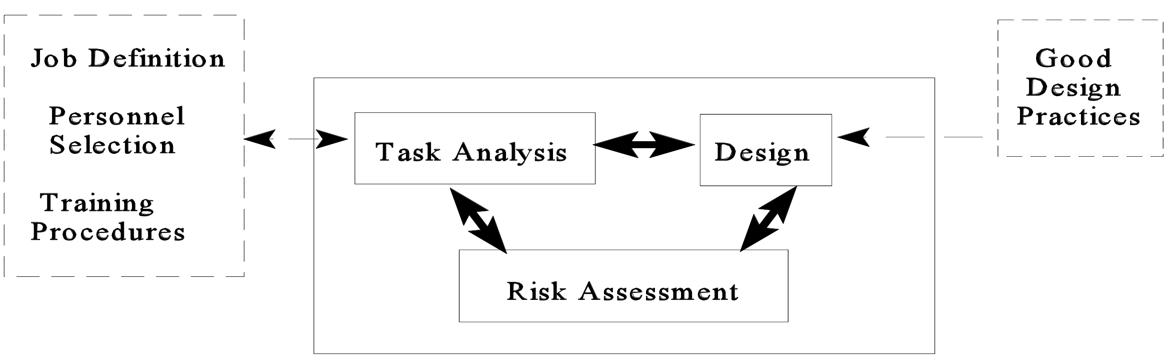


Figure 2: Human Factors Engineering Model



The HFE effort may be graded to the complexity of the system and the Life Cycle Phases by the level of detail used in implementing the elements of the HFE model. The application of the elements of the HFE Model is iterative throughout the system life cycle. The users of this guide should recognize the interactions between the safety requirements and HFE which in many cases have the same objectives.

2.1 HFE Program Planning

2.1.1 Project Assessment

A key planning activity, is to determine how much HFE effort is needed and where it should be focused to obtain maximum benefit. The HFE planning effort should take the form of a top-level project assessment, performed in the Pre-Conceptual Activity and early in the conceptual phase of a project. The assessment is subjective in nature, and for simple projects should be performed by selected project team members, including the end-user of the system. For more complex projects, it is recommended that a Human Factors Engineer be assigned to the project team and lead the HFE assessment. Also a simple system with a lot of human intervention in the operation will require more HFE effort than some fully automated complex system.

A good starting point for assessing the project is understanding the customer/system user's needs and desires. Although many customers may not be knowledgeable of HFE tools and techniques used by the Human Factors Engineer, they will be very concerned with how the completed system will interface with operations and maintenance personnel. Ease of operation and maintenance, personnel safety, and sensitivity to human error are a few of the user concerns ~~of~~ which must be of paramount importance to the design team. In some instances, the users HFE needs are captured in a System Specification, System Requirements Document, or other similar customer-prepared document that contains key user-generated requirements. Most times, however, HFE user needs must be established and clarified during meetings and interviews.

Once user-specific HFE requirements are known, the project is assessed to determine an appropriate level of HFE design support activity. This initial assessment ideally is performed in parallel to concept development activities, or it can be based on the review of existing project documentation if the project has entered the execution phase. Essentially, the assessment helps the design team understand the level and complexity of potential human involvement with operation and maintenance of the planned system. The assessment considers environmental conditions under which operations/maintenance must be performed, system complexity, potential hazards to which humans might be exposed, and the consequences of human error during system operation/maintenance. The following series of questions may be used as an assessment checklist:

1) What is the expected frequency of human operator involvement with the system? Daily, Weekly, Monthly ?

2) What is the perceived “intensity” of human operator involvement with the system (i.e., complex systems generally require more “intense” operator involvement than simple ones)? Low, Medium, High?

3) What is the expected frequency of human maintainer involvement with the system? Daily, Weekly, Monthly ?

4) What is the perceived “intensity” of human maintainer involvement with the system (i.e., complex systems generally require more “intense” maintainer involvement than simple ones)? Low, Medium, High?

5) What skill level of personnel will be expected to operate the system? Unskilled, Moderately Skilled, Highly Skilled?

6) What skill level of personnel will be expected to maintain the system? Unskilled, Moderately Skilled, Highly Skilled?

7) What is the expected population from which operators/maintainers will be selected?

8) Is the system architecture expected to be new and/or unique, or are proven existing technologies, processes, and equipment expected to dominate the design?

9) What Facility Hazard Level(s) is/are expected as a result of the new system (refer to DOE STD 1027)? Category 1, 2 , or 3?

10) Does the potential exist for significant environmental insult due to operator/maintainer error?

11) Does the potential exist for personnel injury due to operator/maintainer error?

12) Does the potential exist for significant equipment damage due to operator/maintainer error?

13) Does the potential exist to incur high costs or to lose a capability deemed critical to a DOE mission?

14) Will operation/maintenance of the system require strenuous physical activity?

15) Will normal operation of the system require personnel to function in environmental extremes? Severe Heat or Cold? Hazardous Materials? Radiation Fields?

16) Will maintenance (planned or unplanned) of the system require personnel to function in environmental extremes? Severe Heat or Cold? Hazardous Materials? Radiation Fields?

Using the checklist as a guide, the design team and the Human Factors Engineer should be able to gauge the appropriate level of HFE effort, activities, and analyses for a given project. In general, proven systems of low complexity with little expected human involvement require little or no formal HFE. The need for focused, more rigorous HFE effort tends to increase with project complexity, uniqueness of the system or facility, expected demands on operators/maintainers, or consequences of errors/accidents. Because this assessment is performed during the conceptual phase of system concept development, most judgements will be based on earlier, similar systems. For original facilities or systems without precedent, completion of the assessment is more problematic and requires a more intense effort. For these types of projects, an experienced Human Factors Engineer should be assigned to the core project team.

2.1.2 HFE Plan

Following completion of the HFE assessment, an HFE Plan should be prepared if additional HFE effort is determined to be required. Typically, the HFE Plan should be as brief as possible while accomplishing the following objectives:

- Document the HFE scope of work for the project, which is derived from agreements with the customer/user and the results of the assessment. The activities (task analyses, design, risk assessment) to be performed in support of the HFE effort should be described and justified. List HFE deliverables.

- Present a cost estimate for the HFE work scope. This estimate should be based on discrete tasks as much as possible, consistent with the stage of design development. Costs should be estimated and presented within the framework of the project work breakdown structure.

- Establish a schedule for performing the HFE activities tied to the project master schedule or lower- tiered project schedules as necessary. HFE tasks must be integrated and sequenced to support project milestones. Where HFE deliverables have been identified, show required completion dates in the schedule.

For small, simple projects, it is likely that the HFE Plan will take the form of a one or two-page memorandum from the Human Factors Engineer or other project team members to the Project Manager. Larger, more complex projects will generally require a more extensive plan, but brevity remains the rule. It is appropriate to include the HFE plan in other planning documents (Project Management Plan, e.g.) where possible. The plan should contain only scope, cost, and schedule information. Philosophical and unnecessary background discussions should be avoided. The Project Manger must agree to the HFE Plan elements and ensure sufficient funding. The plan then becomes the contract by which the HFE effort will be implemented and integrated with the overall project framework.

2.2 HFE Analyses

A number of HFE analytic and evaluation techniques may be utilized as part of the system development process during the project execution phase; the methods discussed in this section are merely representative. Applying these techniques on a graded basis is a matter of varying the degree of emphasis placed on the analysis, or selecting only certain elements of the system to be “human engineered."

2.2.1 Requirements and Functional Analysis/Allocation

Complex projects managed according to systems engineering methodology are defined and refined by requirements and functional analysis and allocation activities (refer to the “Project Execution and Engineering Management Planning Guide”). These activities identify, in increasing detail, “subfunctions” that must be performed by the system under development. The ultimate goal is the ability of enabling the design team to specify a cost-effective system architecture capable of performing all identified functions and meeting all identified system requirements. Requirements/functional analysis is for the most part orchestrated by the systems engineer, but the Human Factors Engineer plays an important supporting role.

The primary role of the Human Factors Engineer during requirements/functional analysis is to help determine whether a system function should be performed and controlled by hardware/software or by human operators/maintainers. Allocation of functions to humans or machines has historically been qualitative in nature (although recent work in human reliability analysis has added a quantitative element) based on relative superiority in performing particular functions (refer to Meister and Rabideau's "Human Factors Evaluation in System Design"). The following guidance can be used when allocating functions to humans or machines:

Humans are Better at	**Machines are Better at**
1. Detecting signals in high noise environments.	1. Responding with minimum lag—machines have microsecond lags, whereas the shortest that can be expected from man is about 200 milliseconds.
2. Recognizing objects over varied conditions of perception—such as, identifying physical objects from remote video signals.	2. Precise, repetitive operations—man is notoriously prone to commit errors in such operations.
3. Handling unexpected occurrences—for instance, selecting alternate modes of operation when equipment malfunctions occur or when unusual environmental conditions are encountered.	3. Storing and recalling large amounts of data.
4. Ability to reason inductively—to diagnose a general condition from specific symptoms.	4. Monitoring functions—man's ability to monitor for infrequently occurring events is very poor.
5. Ability to profit from experiences—to modify responses on the basis of outcomes of prior events.	5. Deductive reasoning ability—the ability to identify a specific item as belonging to a large inclusive class.
6. Originality—the ability to arrive at new and completely different solutions to problems.	6. Sensitivity to stimuli—machines can sense forms of energy in bands beyond man's spectrum of sensitivity; for instance, infrared and radio waves.
7. Flexibility of reprogramming—for example, acquiring new methodological know-how simply by reading printed or verbal procedural directions.	7. Exerting force—for example, operation of large valves in piping systems.
8. Ability to perform when overloaded—such as when saturated with a heavy load of alarm or out-of-tolerance indicators.	

Adapted From Meister and Rabideau, Human Factors Evaluation in System Development

Three major steps in allocating functions to humans and hardware/software have been identified in Van Cott and Kinkade's “Human Engineering Guide to Equipment Design." Each step is briefly described below. The descriptions here are a simplistic treatment for illustrative purposes only; detailed guidance may be obtained from other sources.

1) Examine each identified system function to determine the kinds of capabilities needed to meet system performance requirements. For example, a required function to “monitor liquid volume” in a radioactive liquid low-level waste storage system may be identified, with associated performance requirements that might include minimum time intervals at which measurements must be taken and recorded, availability of the measurement system, environmental conditions under which the measurement system must operate, etc. Each requirement must be reviewed individually and within the context of the others to confirm the appropriateness of allocating the function to a human operator/maintainer or automated operation. In this simple example, the operating environment would initially be expected to be the primary driver. Because the liquid to be measured will generate a potentially hazardous radiation field, it first appears that the function would be best performed automatically. However, if the required measurement interval is only once every 5 years, and dose levels to humans during this task are expected to be well within established limits, humans become a viable, cost-effective alternative. If there is also a requirement that the measuring system be available 90 percent of the time to respond to off-normal and nonroutine activities or to reduce risk, the machine option becomes more viable.

2) Explore potential combinations of human-equipment capabilities through trade-off studies. Functions may be allocated entirely to humans, entirely to equipment, or to some combination of the two. Following the above example, the Human Factors Engineer may propose that liquid level monitoring be an instrumentation (machine) function, with measurements recorded at the required intervals by humans. Another option would be for the instrumentation to perform both the monitoring and recording functions. Potential assignments can be traded-off against each other using Kepner-Tregoe or other similar decision- making methodology. Refer to “Engineering Trade-Off Studies Guide” for further information.

3) Determine a human/equipment design approach that will maximize system cost effectiveness. Following allocation of a function to a human or equipment, a design solution is selected showing “how to” perform the function. This is an iterative process in which alternative potential designs are developed and traded off, with cost typically being a significant evaluative criterion. Again using the

liquid level measurement example, assume that alternative 1 (monitoring by machine, recording by human) was selected based on a formal trade study. Potential design solutions could include instrumentation in the tank with local (i.e., in the proximity of the tank) display of tank levels, or level signals telemetered to some other location for human operators to observe and record. These potential design approaches should then be traded-off, with cost being a highly weighted criterion.

Consisderations for trade offs may include the following:

1. How well will man perform?

2. Compare man versus machine effectiveness?

3. What provisions must be made for each personnel in each alternative?

4. What potential problems will exist for personnel?

5. What are man’s advantages (disadvantages) for each alternative?

2.2.2 Task Analysis

From the Human Factors Engineer’s perspective, task analysis is really a continuation of the functional analysis/allocation activity previously described. According to Rabideau and Meister, task analysis consists of examining the anticipated stimulus inputs to and the required outputs from the system under development and conceptualizing the behavioral mechanisms required to get from the input to the output. Task analysis activities can be quite extensive for original or complex systems; however they should be limited to human-allocated functions with a reasonably high level of perceived importance for most DOE system developments or facility designs. Typically, functions/subfunctions are selected for task analysis on the basis of perceived criticality of human performance, consequence of error, possibility of unsafe system conditions, and possibility of favorable improvements in system operating efficiency.

Once a function or event has been selected for further examination, the Human Factors Engineer begins systematically investigating the task to determine human operator needs and requirements necessary for the successful completion of the task. This is most effectively performed with the aid of a worksheet similar to the example shown below.

Function : (1)	Operate aircraft power plant and system controls
Task : (2)	Control jet engine operation

Subtask (3)	Action Stimulus (4)	Required Action (5)	Feedback (6)	Task Classification (7)	Potential Errors (8)	Allow. Time (9a)	Nec. Time (9b)	Work Station (10)	Skill Level (11)
3.1 Adjust engine r.p.m.	4.1 Engine r.p.m. on tachometer	5.1 Depress throttle control downward	6.1 Increase in indicated tachometer r.p.m.	7.1 Operator task, aircraft commander	8.1 a. Misread tachometer b. Fail to adjust throttle to proper r.p.m.	9a.1 10 sec.	9b.1 7 sec	10.1 Aircraft commander's seat	11.1 Low

From Van Cott and Kinkade, Human Engineering Guide to Equipment Design. Also another reference that may prove to be useful is Kirwan, B. And Ainsworth, L. K., A Guide to Task Analysis, 1992 Taylor & Francis.

Preparing a concise, accurate statement of the task to be analyzed is the next step in the process. In the context of task analysis, SAMSO-STD-77-1, Annex II defines a task as follows.

> "A related set of activities directed toward a purpose. A task has a definite beginning and end. A task involves an individual's interaction with equipment, other people, and/or media. A task, when performed, results in a meaningful product, an advance toward a goal, or completion of a step in a sequence. A task includes a mixture of decisions, perceptions, and/or physical (motor) activities required of a person. A task may be any size or degree of complexity, but it must be directed toward a specific purpose or output. Tasks may include subtasks and related activities/steps, or only activities, or both."

This standard also emphasizes use of specific rules for writing task statements. Task statements should consist of an ACTION VERB + OBJECT + TASK MODIFYING CONDITION. Care should be taken when writing task statements, as this is a very important aspect of the task analysis process.

The task statement is recorded on the worksheet as the basis for further analysis. If a subtask is also identified, it is entered in the first column of the worksheet. Otherwise, the process continues by identifying the "action stimulus," or the event that initiates an action required by a human operator/maintainer. This event is recorded, as is the required human response. The response may be a control movement, a voice communication, or a command. An assessment of the human action is then entered in the "feedback" column.

The "task classification" column may contain a code or other indication of similarity to other tasks. Van Cott and Kinkade recommend a coding scheme that will provide a basis for sorting and classifying tasks according to their similarity. Potential sources of human error, abnormal conditions, and equipment malfunctions can be entered in the "potential errors" column. The information in this column can help the Human Factors Engineer make specific equipment design recommendations to reduce the possibility of design-induced human error. "Allowable time" for a task to be performed is entered if a time requirement has been identified. "Necessary time" refers to the time required for a human operator to perform the task. This information is generally available in operational records or other data bases. If "necessary time" data is not available but considered critical to system operation, mock-ups and models may be constructed to simulate the task and estimate timelines.

The "workstation location" is then identified and recorded on the worksheet. This is the geographic or physical location from which the human operator performs the task under analysis. "Skill levels" required for human actions may be determined by a variety of established techniques and recorded in the last column.

The entire process is then repeated for each step identified in the task. When completed, the end result is a data base that can be used to perform the following activities (from DOE Workshop: Introduction to Human Factors Engineering).

1) Group tasks into positions (i.e., personnel manning).
2) Identify characteristics of or required personnel (strength, visual acuity).
3) Identify training (skill and knowledge) requirements.
4) Identify potential human engineering design problems.
5) Assess system feasibility.
6) Identify communication needs/problems.
7) Identify required job aids/procedures.

Task analysis is a powerful tool for the Human Factors Engineer and can be the backbone of the HFE effort. More detailed references should be consulted for further direction. It is important to note that comprehensive task analysis is a time-consuming (and therefore costly) effort that should be carefully tailored to the system under development.

2.3 HFE in Detailed Design

2.3.1 HFE Design Criteria

Just as traditional engineering disciplines provide discipline-specific design criteria as the basis for detailed equipment design and/or procurement, the Human Factors Engineer specifies design criteria to optimize the human/equipment interface. Because HFE design criteria cuts across discipline lines, it is important that the Human Factors Engineer work as an integrated design team member during design criteria preparation. He/she will assist other design disciplines to ensure that their design criteria incorporate HFE design considerations. Even if no other HFE effort (i.e., analyses) is to be devoted to an engineering project, much benefit can be realized by simply specifying a comprehensive set of human engineering design criteria and ensuring that the criteria are incorporated into the fielded hardware systems.

Data on which human engineering design criteria are based have been collected for a number of years from operational environments and human factors research and development activities. The Department of Defense (DOD) has been at the forefront of HFE data generation and collection, and many applied HFE practitioners consider its "Human Engineering Design Criteria for Military Systems, Equipment, and Facilities", MIL-STD-1472, the premier aggregation of general human engineering design criteria. (There are check list available based on MIL-STD-1472.) This document contains the detailed criteria for good HFE design and a wealth of human anthropometric data, including human body dimensions and reach/stature data for common working positions. Other sources for human engineering design criteria include UCRL 15673, "Human Factors Design Guidelines for Maintainability of DOE Nuclear Facilities," NUREG 0700, "Guidelines for Control Room Design Reviews," and Woodson, Tillman, & Tillman, "Human Factors Design Handbook", 1992.

Detailed HFE design criteria can, in general, be grouped into several major areas.

1) Controls
2) Displays
3) Control/Display Integration
4) Work Space Layout
5) Working Environment
6) Maintainability
7) Labeling
8) User/Computer Interface

Each of these areas is briefly discussed below.

1) Controls - Proper design/selection of control devices is important because control provides a direct physical interface between an operator and the system equipment. Control devices include toggle switches, buttons, continuous rotary controls, rotary selector switches, rocker switches, etc. Furthermore, a multitude of configurations (size, shape, illumination, force feedback) are available for every type of device. It is important that control devices be selected to provide the appropriate control capability, range, and sensitivity within the expected operating environment for all necessary control settings and manipulations. Also, the operating characteristics of controls should conform with operator expectations and experiences. For example, toggle switches energized or "on" should be in up position. Controls should not be vulnerable to inadvertent activation or deactivation and should be properly sized and adequately spaced.

2) Displays - Display devices provide human operators with information about system status and parameter values necessary to meet task requirements during normal, abnormal, and emergency situations. Since task analyses are the basis for establishing operator information needs, these analyses should be reviewed when specifying criteria for display devices. Because of the wide variety of display devices available, great care should be exercised when selecting displays. Displays may be audio or visual, analog or discrete, illuminated, color coded, scaled, or any combination of these. MIL-STD-1472 provides excellent guidance for establishing display criteria in various applications. Additionally, CRTs are being used extensively for system visual displays and are an attractive option under certain conditions.

3) Control/Display Integration - Design criteria for integrating controls and displays into optimal configurations for human operators is at least as critical as specifying the most appropriate control and display devices. The relationship between a control and its associated display should be immediately apparent and unambiguous to the operator. This can be accomplished through proximity of placement, similarity of groupings, coding, framing, labeling, and other similar techniques. Display feedback following a human control action should be immediate. Consideration should be given to the control/display ratio, i.e., the relative movement of a display indication in response to a given control input, for continuous adjustment controls. Again, MIL-STD-1472 contains detailed design criteria for control/display relationships. A newer resource for software issues is ISO 9241.

4) Work Space Layout - Work space layout refers to the physical configuration of areas in which humans are required to perform operations and maintenance tasks. Specific work space design is based on knowledge of the tasks be performed (from the task analysis), but in general, placement and dimensions of equipment cabinets, consoles, workstations, and work surfaces (seated and standing) are all of primary concern when specifying design criteria for work spaces. Adequate visual and physical access to the hardware must be provided, and work spaces should be designed for compatibility with the anthropometric characteristics of the anticipated user population (ergonomics).

5) Working Environment - Work spaces can be located outdoors or within environmentally controlled structures. or outdoors. In either case the Human Factors Engineer must be concerned with the work space environment. Illumination levels adequate for the task(s) being performed must be provided for in the design. Guidelines for appropriate lighting levels are contained within MIL-STD-1472 as well as other HFE design criteria documents. Heating, ventilation, and air conditioning systems must be designed according to generally accepted HFE criteria. Ambient noise must not cause personnel injury or fatigue or interfere with voice or other communications. Vehicles/equipment must be designed to control the transmission of whole body vibration to levels that will permit safe operation and maintenance.

6) Maintainability - Equipment design has been found to have a consistently greater effect on maintenance efficiency than such personnel variables as aptitude or training (Van Cott and Kinkade). Specifying appropriate HFE design criteria for equipment/system maintainability should therefore be a high priority during system design. Standard parts and tools should be used to the maximum extent possible, and equipment should be replaceable as modular packages. The equipment should be designed to facilitate rapid and positive fault detection and isolation of defective items to permit prompt removal and replacement. Physical and visual access for maintenance activities must be provided. In essence, all of the considerations for HFE design of operations should apply to design for maintainability. In addition to MIL-STD-1472, UCRL 15673, "Human Factors Design Guidelines for Maintainability of DOE Nuclear Facilities" is a good source of maintainability design criteria.

7) Labeling - Proper labeling of system components and equipment can enhance operator/maintainer performance and substantially reduce the probability of human error. Labels should concisely and unambiguously indicate the function or purpose of the item labeled. Information not necessary for operation or maintenance should not be included on the label. Label design should be easy to understand and be consistent across systems/equipment. Permanent labels should be designed so that conditions and use will not destroy the label. For process mimic displays, care should be taken to ensure correct display labeling that facilitates operator understanding is used.

8) User/Computer Interface - The use of computers and process controllers as the human operator/equipment interface is the rule for complex systems. Well designed computer interfaces can lead to highly effective operation by humans; likewise, poorly designed interfaces can result in error-filled performance. Examples of the human/computer interface include software operation, screen/display design, and data entry devices. Smith, S. L. & Mosier, J. N. “Guidelines for Designing User Interface Software”, ESD-TR-86-278, 1986 contains extensive guidance for human/computer interface design.

2.4 HFE Test and Evaluation

The purpose of HFE test and evaluation (HFTE) for new or modified systems and facilities is to verify that the constructed system (hardware, software, and procedures) incorporates good HFE design features, and that those features result in a system that is easily and safely operated and maintained by humans. An effective HFTE program is the result of proper planning and thoughtful implementation.

2.4.1 HFTE Planning

HFTE planning should focus on activities required to verify that the system can be operated and maintained by personnel in the intended operating environment. The HFTE program is most effective if planned in parallel with the system hardware/software test and evaluation program (refer to "Test and Evaluation Guide”) to take advantage of scheduled design reviews, simulations, development tests, demonstrations, procedure development and validation, and system pre-operational checkouts. HFTE planning is an extension of HFE program planning described earlier. An HFTE Plan should be brief but at a minimum cover the following topics.

1) What is to be evaluated and/or tested from an HFE perspective.
2) The schedule for the test/evaluation activity.
3) The test or evaluation methods to be used.
4) How test/evaluation results will be reported.

Each of these areas is further discussed in the following section.

2.4.2 HFTE Implementation

1) What to Test/Evaluate - Any aspect of the system under development that has a human operator/maintainer interface is a candidate for HFTE scrutiny. However, budgetary limitations will of necessity restrict the level of HFTE effort to areas where specific HFE system requirements exist, or to areas where human performance is considered critical to safe, reliable operation of the system, or to areas where a significant cost/benefit is perceived. This philosophy, therefore, initially focuses the HFTE effort on the same functions and tasks deemed important enough to warrant HFE task analysis. As resources allow, HFTE should be expanded to cover tasks expected to be performed frequently, and operations/maintenance activities that are new or significantly different from earlier tasks with previous systems.

2) HFTE Timing - Although the HFTE effort can be expected to occur throughout the implementation phase of the engineering project, the greatest return will be realized during detailed design activities. This is the time when design drawings are created that, when approved, will establish baseline equipment configurations , making changes and enhancements to the design quite difficult (and expensive). The HFTE effort should be integrated with the overall project test and evaluation schedule, including scheduled design reviews, prototype hardware development, and pre-op and operational testing wherever possible.

3) HFTE Methods - Many techniques are used for HFTE, and it is beneficial to identify, as part of HFTE planning, those that are to be used during system development. As potential system architectures are identified, HFTE tasks may include the development of hardware mock-ups to simulate human/equipment interface(s) to identify potential HFE deficiencies. Rapid prototyping methodologies are another tool. They allow the Human Factors Engineer to simulate human/machine interfaces graphically via computer, and can eliminate the need to fabricate full-size physical models and mock-ups. The results are used as input to trade studies for selecting baseline equipment configurations.

The most common HFTE evaluation technique is the review of design drawings and specifications by the Human Factors Engineer at various stages during detailed design; for example, during scheduled design reviews when the Human Factors Engineer can evaluate proposed hardware configurations for incorporation of HFE design criteria. As design documents are translated into engineering models or field hardware, it is beneficial for the Human Factors Engineer to inspect the hardware items before they reach the field in an operational configuration, once again to ensure that good HFE design criteria have been incorporated. This inspection usually occurs in conjunction with other engineering development testing. Use of HFE checklists, such as the MIL-STD-1472 Checklist prepared by the Crew System Ergonomics Information Analysis Center (CSERIAC), are quite helpful in performing these evaluations. Another resource is the U. S. Army Test & Evaluation Command, "Human Engineering Test Procedures" (TOP-1-2-610).

Once the equipment items have been assembled in a pre-operational or operational environment, the HFTE effort should consist of direct observation of operationally configured tasks to ensure fulfillment of HFE goals and requirements. This permits the Human Factors Engineer to collect data and evaluate how operations/maintenance personnel interact with the entire system, including operating and maintenance procedures. Data collection during this phase of HFTE can include illumination and noise levels, human force/strength requirements, task timelines, etc. It is common to videotape selected tasks as part of HFTE observation. Evaluation of the adequacy of procedures in an operational setting is also a critical HFE task that should be accomplished at this time. Observation of field operations also provides the opportunity for informal interviews of operations and maintenance personnel. These individuals are the most affected by human factors design deficiencies, and can provide valuable input as to improving human/equipment interfaces.

4) HFTE Reporting - Formats for reporting HFTE results will vary, as will the level of detail. For example, a relatively simple system or equipment item evaluated during the design phase may require only a confirmation memo. The report should briefly address what was evaluated, and should list any HFE design deficiencies or concerns identified by the Human Factors Engineer. Other, more complex systems that have undergone a more rigorous HFE application during design may require preparation of a Human Engineering Design Analysis Report (HEDAR) or similar report. This report discusses the equipment analyzed and describes the human/equipment interfaces in an operational setting. Deficiencies and areas identified for HFE improvement should be included,as well as suggested solutions for eliminating problem areas.

For DOE projects requiring preparation of Safety Analysis Reports (SARs) in accordance with DOE Order 5480.23, NUCLEAR SAFETY ANALYSIS REPORTS, documentation in the SAR is required to show that a "...systematic inquiry into the safety importance of reliable, correct, and effective human/machine interactions" has been made. Additional details with respect to report contents are given in DOE 5480.23.

For HFTE work consisting of direct observation of personnel activities, preparation of HFTE test records are appropriate for documenting results and HFE deficiencies.

SAMSO-STD-77-1 contains a HFTE Test Record Form that can be modified as needed for non-DOD systems and projects.

2.5 Operation & Maintenance

It is not correct to assume that once a plant is in operation, that all factors that impact human performance have been designed in, or found through the Test and Evaluation process. A program should be established for use during the operational life of the product to monitor human performance problems and correct them. Human performance impacts should be considered for all instrumentation and control modifications, both equipment specific and the impact of these modifications on overall tasks and performance. Lessons learned programs that constantly monitor events with human performance components, such as INPO's Human Performance Enhancement System (HPES) or NRC's Human Performance Investigative Process (HPIP) should be used to detect human performance problems that need correction. To assure that over several years many small changes have not introduced major human performance problems, updating the control room design review may be prudent.

3. MEASURING FOR RESULTS

Several parameters, if measured during system operation and maintenance, can provide indicators as to the effectiveness of the HFE program. These parameters include:

- number of incidents/accidents reported;
- human error rates;
- number of design changes or retrofits for ease of operation;
- mean-time-to-repair;
- frequency and level of operator training/re-training required; and
- subjective measures of operator/maintainer opinions of system operability.

As with all metrics, care must be taken to ensure the validity of HFE performance measures.

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4. SUGGESTED READING

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5. DEFINITIONS

For a complete listing of the definitions for major terms used in this Guide, see the Consolidated Glossary.

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6. ASSISTANCE

Questions concerning this Guide may be referred to the Office of Field Management in Washington, D.C. at (202) 586-4041. Human Factors questions may be referred to Dr. Robert Waters in EH-53 at (301) 903-5755.

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7. RELATED TRAINING

Lawrence Livermore National Laboratory, Introduction to Human Factors Engineering Course