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(Revision of
IEEE Std 1023-1988)

1023™

IEEE Recommended Practice for the Application of Human Factors Engineering to Systems, Equipment, and Facilities of Nuclear Power Generating Stations and Other Nuclear Facilities

IEEE Power Engineering Society

Sponsored by the
Nuclear Power Engineering Committee

IEEE

3 Park Avenue, New York, NY 10016-5997, USA

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Nuclear Power Engineering Committee
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Abstract: This document provides recommended practices for applying human factors engineering (HFE) to systems and equipment that have significant human interfaces in nuclear power generating stations and other nuclear facilities.
Keywords: control room design, ergonomics, human engineering, human error, human factors, nuclear power, nuclear facilities, task analysis, validation, verification

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Introduction

This introduction is not part of IEEE Std 1023-2004, IEEE Recommended Practice for the Application of Human Factors Engineering to Systems, Equipment, and Facilities of Nuclear Power Generating Stations and Other Nuclear Facilities.

The need for the application of human factors engineering (HFE) in the life cycle activities of nuclear power generating stations and other nuclear facilities has been demonstrated by plant operating histories and regulatory and industry reviews. Prior to the incident at Three Mile Island-Unit 2 (TMI-2) in 1979, little guidance for the application of HFE in nuclear facilities existed. Evaluation of the TMI-2 incident revealed that better application of HFE in nuclear power plant design could contribute to reducing human errors, mitigating events, and preventing accidents. Based on this potential for improved nuclear safety, the Nuclear Regulatory Commission instituted guidance for the incorporation of HFE principles in the design of nuclear power plants. Department of Energy laboratories and industry groups such as the Electric Power Research Institute and the Institute of Nuclear Power Operations have also provided research, studies, and methodologies to support the application of HFE to further the safe operation of nuclear facilities.

This Recommended Practice, IEEE 1023-2004, is provided to promote the systematic application of HFE in nuclear facility programs. It is intended to serve as the top-level program document under which additional standards are written or referenced to address specific technical needs. As the top-level document, it is beyond the scope of this Recommended Practice to offer the detailed guidance that is needed to support the various activities that may be implemented by such programs. However, since TMI 2, detailed guidance on many relevant topics has been provided by numerous sources. Such guidance may be accessed, for example, through the Bibliography given in Annex A.

This revision takes a more flexible approach than did its predecessor. A more flexible approach was deemed necessary to accommodate the Recommended Practice's expanded scope, which now 1) includes nuclear facilities besides power plants, and 2) addresses the entire facility life cycle (formerly just the design process). Flexibility was also warranted to balance the increased rigor of a Recommended Practice over a Guide, and to resolve the diversity of views existing on the Subcommittee.

In the revision process, efforts were made to add practical substance, to be compatible with other industry standards, and to consider current industry trends. A particular concern was to prepare for the increasing role of risk-informed and risk-based assessment in nuclear facility licensing and operation. The key notion of "significant human interface", retained from the original guide, was thus refined to incorporate and relate the concepts of acceptable performance, human error, and facility risk.

IEEE Std 1023 was initially published in 1988 as an IEEE Guide. The current revision was begun under Working Group 7.1 of Subcommittee 7, Human Factors and Control Facilities, and was completed under Working Group 5.1, Human Factors Applications and Methods, of Subcommittee 5 (SC-5) Human Factors, Control Facilities, and Reliability, of the Nuclear Power Engineering Committee of the IEEE.

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IEEE Recommended Practice for the Application of Human Factors Engineering to Systems, Equipment, and Facilities of Nuclear Power Generating Stations and Other Nuclear Facilities

1. Overview

1.1 Scope

This document provides recommended practices for applying human factors engineering (HFE) to systems and equipment that have significant human interfaces in nuclear power generating stations and other nuclear facilities.

1.2 Purpose

This document provides recommended practices to engineering personnel for development of integrated programs for applying human factors engineering to the design, operation, and maintenance of nuclear power generating stations and other nuclear facilities.

2. Normative references

The following referenced documents are indispensable for the application of this document. For references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ANSI/ANS 3.1, Selection, Qualification, and Training of Personnel for Nuclear Power Plants.[1]

ANSI/ANS 3.2, Administrative Controls and Quality Assurance for the Operational Phase of Nuclear Power Plants.

[1] ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (http://www.ansi.org/).

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ANSI/ANS 3.5, Nuclear Power Plant Simulators for Use in Operator Training.

ANSI/ANS 58.8, Time Response Design Criteria for Safety-Related Operator Actions.

IEEE Std 497™, Standard Criteria for Accident Monitoring Instrumentation for Nuclear Power Generating Stations.[2, 3]

IEEE Std 603™, IEEE Standard Criteria for Safety Systems for Nuclear Power Generating Stations.

IEEE Std 845™, IEEE Guide for the Evaluation of Human-System Performance in Nuclear Power Generating Stations.

IEEE Std 1082™, IEEE Guide for Incorporating Human Action Reliability Analysis for Nuclear Power Generating Stations.

IEEE Std 1220™, IEEE Standard for Application & Management of the Systems Engineering Process.

IEEE Std 1289™, IEEE Guide for the Application of Human Factors Engineering in the Design of Computer-based Monitoring and Control Displays for Nuclear Power Generating Stations.

IEEE P1586™ (D1.0), IEEE Draft Recommended Practice for Human Interactions with Operating Experience Programs for Nuclear Facilities. [4]

3. Definitions

For the purposes of this recommended practice, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standards Terms, Seventh Edition*, should be referenced for terms not defined in this clause.

3.1 displays: Devices that convey information for perception by users, including but not limited to digital and analog instruments, computer screen pages, annunciator tiles, audible alarms, status lights, mimics, overviews, and indicating features of control devices.

3.2 human factors engineering (HFE): An interdisciplinary science and technology concerned with the process of designing for human use.

3.3 human error: Failure of human task performance to meet specified criteria of accuracy, completeness, correctness, appropriateness, or timeliness.

3.4 life cycle activities: The activities performed in order to plan, design, test, operate, maintain, and decommission any given facility.

3.5 significant human interface: A point of interaction between users and equipment, facilities, software, or documentation, where the resulting human performance is necessary for acceptable system performance, and the probability of human error contributes significantly to facility risk.

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3.6 task: An orderly set of human actions or work behaviors that are performed to achieve a specific result.

3.7 usability: For a given human interface, the quality that acceptable human performance on necessary tasks can be readily achieved and sustained.

3.8 users: All members of the facility's technical staff, including but not limited to licensed operators, who perform testing, operations, maintenance, or decommissioning tasks on systems or equipment.

4. Systematic application of human factors engineering

Human factors engineering (HFE) should be planned as an integral part of life cycle activities. HFE should be implemented as an explicit part of coordinated planning (6.2), along with the other disciplines and processes that are required by any given activity. Planning for HFE activities should consider:

a) Past experience and current practices, to identify relevant HFE concerns

b) Applicability of available HFE studies, reports, guidelines, and methods

c) Coordination of disciplines/groups/organizations to determine and perform HFE activities

d) Development of plans and tools needed to perform HFE activities

e) Trade-offs among HFE considerations and other life cycle activities

HFE should be an ongoing consideration in the evaluation or modification of existing designs, or in the development of new designs. Since the application of HFE affects interrelated life cycle activities, HFE should be considered as early as possible. Follow-up reviews should also be planned, to determine the effectiveness of HFE implementations.

5. Basic considerations of human factors engineering

Human factors engineering activities should address the following basic considerations of significant human interfaces throughout the project life cycle:

a) Tasks

b) Work environments

c) Equipment

d) Personnel

e) Organization and support

These interrelated considerations are portrayed in Figure 1, and are addressed individually in 5.1 through 5.5.

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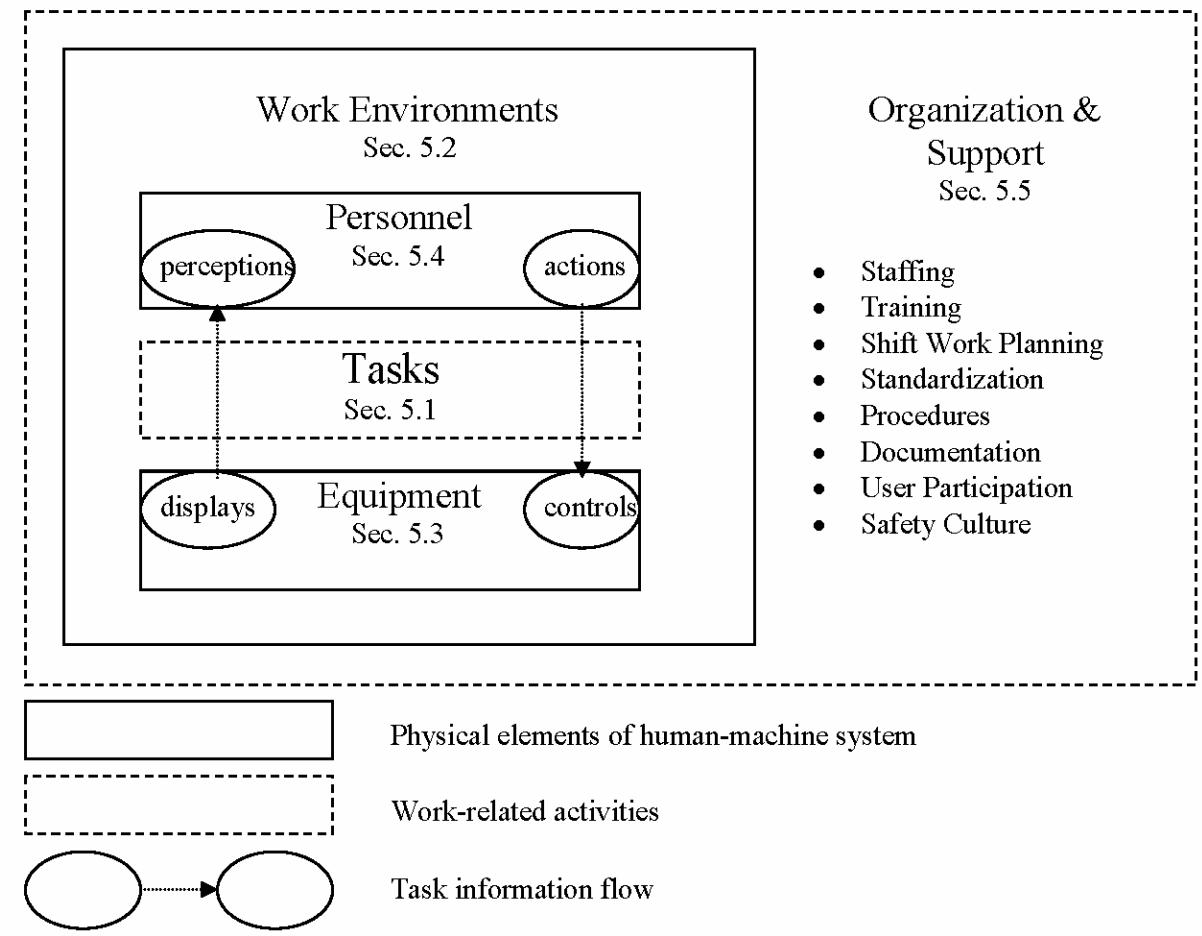


Figure 1— Basic considerations of HFE

5.1 Task considerations

To ensure reliable human performance, the following considerations of tasks, task performance, and task support should be addressed in life cycle activities. Also see 6.3.3, Task Analysis.

5.1.1 Role of the user

The role of the user in a system consists of the human activities and responsibilities performed to achieve safe and effective system operation. This may be established by regulations or standards, by physical, environmental, or temporal constraints, or by the precedent of similar designs proven by operating experience. The user's role and the function of the associated equipment/process (6.3.2) should be complementary, so that the combined system is safe and effective. In terms of human performance, a user's role is acceptable if the required tasks can be achieved readily within normal human capabilities and limitations.

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5.1.2 Task loading

Task loading is the extent to which ongoing work taxes the mental and physical capacities of personnel, individually or as a team. During extended periods of over- or under-load, humans typically make more errors and/or become less productive. For example, over-loading may occur when attention must be divided among too many tasks, or when rapid response rates must be sustained. Under-loading may occur with monotonous tasks such as monitoring for infrequent events, leading to boredom, inattention, and disengagement. For significant human interfaces, acceptable task loading should be confirmed by analysis, testing, and/or user feedback.

5.1.3 Human reliability

Environments, systems, equipment, and work procedures influence the likelihood of human error. Human reliability is concerned with the causes, probability, consequences, and reduction of human error. Human reliability relates to many HFE considerations; some important issues are discussed below.

5.1.3.1 Performance criteria

Adequate performance on required tasks should be defined by performance criteria. Performance criteria should be compatible with human capabilities and limits. Performance criteria should incorporate reasonable margins with respect to the consequences of inadequate performance.

5.1.3.2 Task Feedback

Feedback is a returned indication of the response of an object to control input. Feedback is particularly important for remote operations, where direct observation of results is limited or absent. Feedback provides users with means to confirm results, to guide subsequent actions, to detect anomalies, and to recover from errors. Human errors are often linked to inadequate task feedback. Important characteristics of task feedback that should be considered include:

a) Direct indication – Feedback should be driven by final, not intermediate, processes.

b) Positive indication – Absence of indication should not be used as feedback.

c) Timeliness – Feedback should be prompt; delays reduce effectiveness.

d) Sufficient precision – Feedback should meet the precision requirements of the task.

5.1.3.3 Adaptability and error

In contrast to machines and their relatively high reliability, adaptability is the main strength of the human as a systems component; these features are complementary in effective design. However, human adaptability should not be relied on to achieve necessary system performance or to offset design deficiencies. Unplanned activities may lead to other undesirable results. Validation exercises (6.5.5.3) should be demanding so that design deficiencies are not masked by routine human adaptations.

5.1.3.4 Error reduction and tolerance

Designers should strive to eliminate the opportunity for users to commit errors with unacceptable or undesirable consequences. However, given that human error cannot be eliminated completely, system and equipment designs should tolerate anticipated human errors such that expected consequences are acceptable. Strategies for improving tolerance of the facility to human error include:

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a) Apply barriers to prevent errors with unacceptable consequences (e.g., physical guards or stops; logical and mechanical interlocks; failsafe designs; or administrative controls).

b) Where high task loading is a concern,

   1) Increase time margins for action, or

   2) Decrease task performance requirements, or

   3) Make added resources available.

c) Apply buffers to avoid errors with undesirable consequences (e.g., redundant structures or processes; time delays; reversible, confirmatory, or staged actions).

d) Address significant findings from human reliability analysis as appropriate in design, procedures, and training.

e) Automate the task.

5.2 Environmental considerations

The following considerations of physical work environments should be addressed in life cycle activities. In each area, the applicable design basis should address strategy and provisions for continued work anticipated under degraded environmental conditions. Environmental requirements (6.4.5.4) should ensure that the design will accommodate personnel and support task performance under all necessary and anticipated conditions.

5.2.1 Temperature, airflow, and humidity

A comfort zone for personnel can be defined by appropriate ranges of temperature, airflow, and humidity. These factors interact and must be addressed jointly. Occupants' preferences may vary, for example, due to weather, plant mode, or the type of work to be performed. In addition, while personnel health and safety shall be protected, the comfort zone may be affected by equipment requirements or other environmental constraints. Environmental controls and/or other accommodations should maintain air quality suitable for anticipated work. Heating, ventilation, and air conditioning (HVAC) specialists should be involved in the necessary design and evaluation processes.

5.2.2 Illumination and acoustics

Human physiology and task performance are best suited by certain ranges of ambient light and sound. Light and sound may also offer aids to alertness (5.5.3.2). Adequate levels, spectra, and source positions should be considered during design and confirmed after installation. Also, interactions between lighting and visual display characteristics, and between sound levels and audio display characteristics (including voice communications), should be considered. Lighting and acoustical specialists should be involved in necessary design and evaluation processes.

5.2.3 Size, geometry, and layout

Task performance can be affected by the size and geometry of the workspace (e.g., a control room) and by the layout of the workplace (e.g., a workstation and its immediate surroundings). The number of personnel, the patterns of traffic and communications, and any bulky or restrictive clothing that may be required in the workplace should be considered. Accessibility is a main concern, and may require tradeoffs among competing task demands such as importance to safety, time constraints, and frequency of use. Equipment usability (5.3), anthropometry (5.4.2), error tolerance (5.1.3.4), and shift turnover 5.5.3.3) are related issues that should be considered.

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5.2.4 Personnel safety and environmental hazards

Measures should be employed to prevent and to mitigate hazardous exposures in the workplace so that personnel safety is assured. Typical methods employ training in and use of warnings, barriers (5.1.3.4), protective clothing, and safety equipment. Mandatory equipment safety requirements and limits on health-threatening agents, toxins, substances, and energies are specified by federal regulations (e.g., of the Nuclear Regulatory Commission, the Occupational Safety and Health Administration, and the Environmental Protection Agency.) In general, unless more specific information is available, the as-low-as-reasonably-achievable principle should be applied to manage occupational exposures to health-threatening agents. System design description documents should include expected occupational exposure sources and levels, along with the basis for countermeasures and protective features provided by the design.

5.3 Equipment considerations

The following considerations of equipment usability should be addressed in life cycle activities.

5.3.1 Available content

The contents of display and control features that the design makes available to users should be:

a) Individually necessary to perform a task;

b) Collectively sufficient to perform all tasks.

Available content is specified by design requirements (6.4.5.1) and is confirmed by availability verification (6.5.5.1).

5.3.2 Suitable format

The format of display and control features should provide suitable support in terms of:

a) Personnel characteristics

b) Task demands

c) Standards & conventions at the facility

d) Other applicable HFE guidance

Suitable format is specified by design guidelines (6.4.1) and is confirmed by suitability verification (6.5.5.2). Suitability guidance addresses display and control characteristics such as clarity, simplicity, and compatibility of format. For example, digital readouts may be appropriate for high-precision readings but may be inappropriate for status check readings, for rapidly comparing separate readings, for monitoring data over time, or for rapidly changing data.

5.3.3 Operability

The equipment as a whole should permit necessary tasks to be performed effectively under actual circumstances of use. Necessary tasks and operability criteria are specified through performance requirements (6.4.5.3). Operability is confirmed via usability validation. (6.5.5.3).

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5.3.4 Maintainability and testability

In addition to production activities, shutdown, maintenance, and testing activities should be considered from the perspectives of HFE and usability. Maintenance and testing add considerations such as:

a) Space requirements for equipment pull and laydown activities;

b) Ease of equipment access, removal, disassembly, reassembly, and installation;

c) Buffers to avoid impact of in-service equipment removal and restoration;

d) Barriers to prevent erroneous equipment assembly and installation.

5.3.5 Reliability and failure

Given that failure of systems and equipment cannot be eliminated completely, their designs should support human recognition of, and response to, failures. Note that equipment reliability and human reliability interact: Highly dependable equipment can encourage trust, but also can discourage the recognition of malfunctions. Therefore, designers of systems and equipment should address:

a) How users can determine when a system or piece of equipment has malfunctioned, and

b) How users should respond when such a malfunction is indicated.

System and equipment failures create abnormal and more error-likely conditions for decision and action. Thus, appropriate training and qualification (6.6.5) should be provided to reduce the likelihood of erroneous responses to system and equipment failures.

5.4 Personnel considerations

The following considerations of human beings should be addressed in life cycle activities.

5.4.1 Physiological limitations

For strenuous or repetitive manual tasks, the physiological limitations of the human body such as strength, endurance, range of motion, and the capability to apply force should be considered. Specific mandatory limits may exist based on environmental considerations.

5.4.2 Anthropometry

The workplace layout should be compatible with the body dimensions of users in terms of reach distances, seating heights, lines of sight, and physical clearances. Anthropometric data can vary widely between groups based on age, gender, ethnicity, or other factors. Applicable anthropometric data should be included by design guidelines (6.4.1), so that workplace dimensions will accommodate a wide range (e.g., 90%) of the expected user population.

5.4.3 Sensory perception

The output level/intensity of any visual or auditory display should be significantly above absolute sensory thresholds and below exposure-adjusted tolerance limits. Also, the difference between a signal and expected noise levels, or the difference between two signals, must be significantly above relative sensory thresholds, to ensure that the

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differences are noticeable. Appropriate protection should be applied to prevent exposure to excessive light or sound energies (5.2.4). Applicable guidance should be included by design guidelines (6.4.1).

5.4.4 Cognition

The nature and limitations of human cognition should be considered in design. Key examples include that:

a) Short-term memory has very limited capacity;

b) Long-term memory has very large capacity, but recall is unreliable;

c) Decision-making shows characteristic bias and conservatism.

As compared to machines, humans are more flexible, but less reliable. Thus, some tasks are better allocated to systems and equipment, such as the sustained monitoring of setpoints, the performance of repetitive computations, and the execution of rapid, fixed sequences. Where real-time constraints permit, the use of memory aids and clear decision criteria via on-line references or specified documentation generally is preferable to unaided task performance.

5.4.5 Knowledge and abilities

The knowledge and abilities expected of personnel should meet or exceed the applicable task requirements. This is primarily accomplished by technical training and qualification programs (6.6.5). However, sufficient trainee capabilities and basic skills should be assured through the trainee selection process.

5.5 Organization and support considerations

The following organizational, social, and programmatic considerations of nuclear facility operation should be addressed in life cycle activities.

5.5.1 Staffing

The number of technical staff selected, trained, and qualified must be sufficient to meet the job requirements of the facility.

5.5.2 Training

Specific knowledge and abilities required to operate the facility are provided by training and qualification programs (6.6.5). These programs establish competence and maintain proficiency (i.e., speed and accuracy) particularly for tasks that are infrequent or that must be performed with high reliability under stress.

5.5.3 Shift work planning

Human physiology and behavior are disturbed by shift work. Like so-called “jet lag”, any shift change (e.g., from days to nights) tends to disrupt the cycle of sleep and wakefulness established by the human body. An individual’s accommodation to shift change can vary from days to weeks. Even if shift changes are eliminated, workers may never fully adjust to the effects of working at night. Thus, many shift workers suffer some degree of chronic performance impairment, such as increased drowsiness, stress, and error. To address these problems, the following results from shiftwork studies should be considered.

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5.5.3.1 Shift schedules

Periodic shift rotation can help alleviate some of the social and physical concerns of shift workers. Studies suggest that forward rotations (successively later starts, e.g., afternoons to nights to mornings) and slow rotations (a week or more per shift) may be easier to adjust to. Larger staff complements allow more scheduling flexibility. Extended shifts (e.g., 12 hours vs. 8 hours) have produced mixed results. They are preferred at some facilities, but they may reduce flexibility (e.g., for schedule changes and overtime). In general, if fatigue noticeably impairs performance, work schedules and/or assignments should be revised.

5.5.3.2 Alertness aids

While not a substitute for adequate rest, alertness aids can be effective for some shift workers. Beneficial stimulation can be provided by work that requires muscular activity, by occasional use of mild stimulants (e.g., caffeine), and by environmental factors such as cool temperatures, bright lighting, and engaging (but not monotonous or distracting) sounds. Provisions for strategic napping should be considered for personnel whose vigilance is critical. Training should address methods to improve adjustment to shift change and alertness on shift, including effective lifestyle accommodations and proper use of alertness aids.

5.5.3.3 Shift turnover

Design of applicable workspaces should accommodate two shifts during turnover. Formal turnover methods should be used to assure that the oncoming shift has received and understands current status of all systems, equipment, and evolutions.

5.5.4 Standardization

Standard conventions (e.g., for measurement units, information coding, and device configuration) and standard nomenclature (terminology, abbreviations, and acronyms) should be applied in equipment design, technical documents, and training materials. Standard selections should avoid conflict with existing conventions and population stereotypes. Local standards should be formally approved and maintained.

5.5.5 Procedures

The content of procedures should correspond to the knowledge and abilities provided to personnel by training and qualification programs (6.6.5). Consideration should be given to how the tasks to be performed should be accomplished and how errors in performance may be avoided (6.3.3). Procedure documentation should include appropriate explanations, such as the bases for particular actions and expected responses. Content should be technically correct and complete. Format should conform to the applicable Procedure Writer's Guidance (6.4.2).

Operating procedures, in particular, should be verified to be correct in terms of available content and suitable format. Prior to issue, operating procedures should be validated to be usable under appropriate test conditions (6.5.5.3).

5.5.6 Documentation

Required documents such as technical manuals, procedures, and as-built drawings should be specified and prepared prior to operation. After a system or equipment is commissioned for service, required documents should be kept current. Documentation should reflect standard conventions and nomenclature at the facility. Document issue-for-use should be administratively controlled (6.6.1).

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5.5.7 User participation and acceptance

In considering usability, the most practical source of information about equipment and its operation is often experienced users. As early as possible, seek the input of users, address their concerns, provide them with feedback, and solicit their acceptance. Users should be involved routinely in major change processes and needs assessments (6.3.1), to ensure that new or revised systems will be effective and acceptable.

5.5.8 Communication and coordination

Communication and coordination are necessary for successful teamwork. To this end, provisions (e.g., phones, speakers, noise hoods, pathways, furniture, workspaces, etc.) and work practices should be established and maintained by the facility so that task support is sufficient in all modes of operation. See also related environmental considerations (5.2.2 and 5.2.3) and task analysis (6.3.3).

5.5.9 Safety culture

Organizations should strive to maintain a culture that values “safety first”. Training and appropriate reinforcement for desired (e.g., safety-promoting) behaviors should be considered, obstacles to desired behaviors (e.g., fear of reprisal) should be reduced, and undesirable (e.g., unsafe) behaviors should be prevented or discouraged.

6. Implementation of human factors engineering activities

The implementation of HFE in the life cycle activities of nuclear facilities should employ an integrated, systematic approach that considers the human as an integral part of the overall system. The following subclauses present a framework and associated HFE activities as typically are implemented by such facilities for significant human interfaces. The choice and relation of activities to be implemented may vary, and should be tailored to the needs and constraints of the specific facility. Organizations responsible for implementing HFE activities should maintain programs to apply selected HFE activities of the following subclauses, such that the basic HFE considerations of Clause 5 are addressed throughout facility life. Annex A provides additional sources of information on the HFE activities presented below. See IEEE Std 1220 for additional information on the overall Systems Engineering Process. [5]

6.1 Engineering process model

Typical HFE activities for significant human interfaces are presented in terms of a generic engineering process model in Figure 2. This simplified Star model connects each of the following components to every other component in the model:

- Planning
- Analysis
- Specification
- Testing and evaluation
- Operations and maintenance

[5] Information on references can be found in Clause 2.

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Though a natural tendency exists for activities to progress clockwise in Figure 2, the Star model allows for diversity of acceptable processes in actual situations. Any particular process will require more details for implementation. Implementation details should assure the adequacy of specific processes based on situation- and organization-specific needs. The Star model is provided for explanation only, not as a recommendation for any particular engineering program or process. Annex B presents several examples to illustrate how HFE activities may be related in engineering organizations and processes.

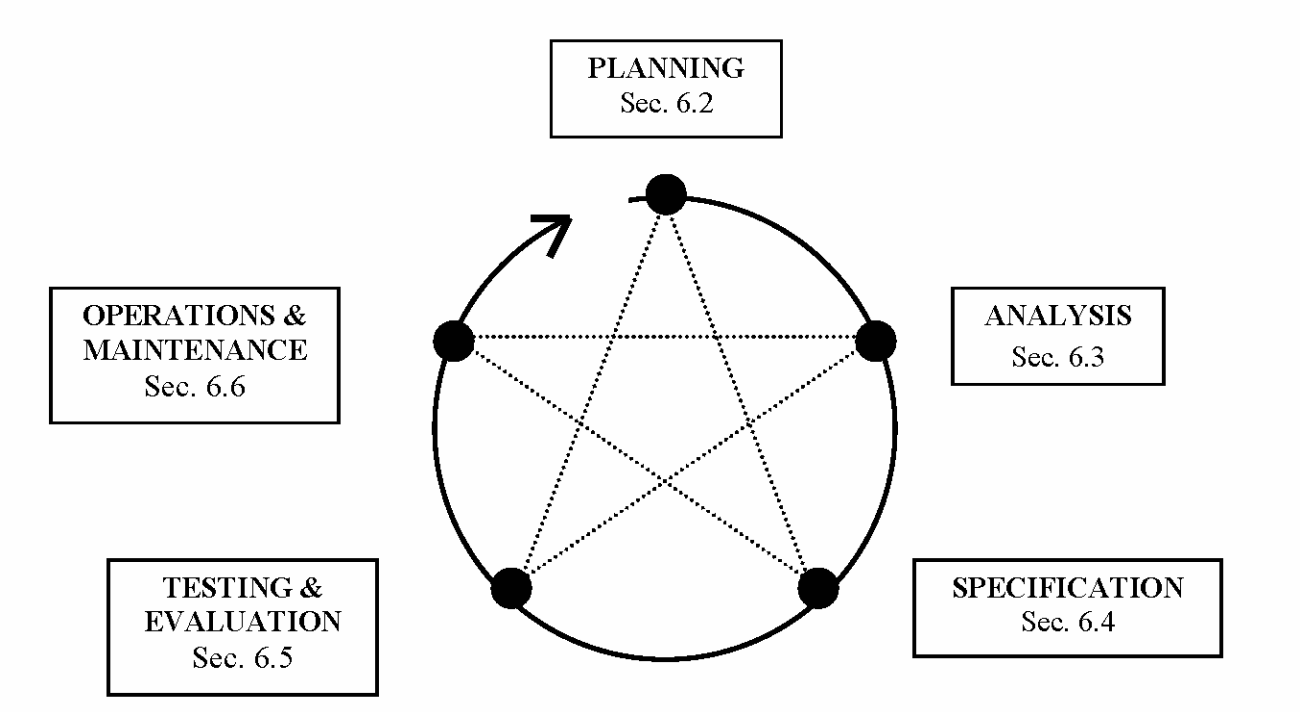


Figure 2—Engineering process model

6.2 Planning

Program plan(s) should be used to implement HFE in areas such as procedure development, design modification, and training delivery. Both new and existing facilities should utilize program plans to:

- Support a systematic approach to HFE throughout facility life
- Support integration of HFE with overall planning and systems engineering processes
- Formalize HFE activities, scope, responsibilities, milestones and deliverables
- Apply HFE early in development to reduce the need for process iterations
- Provide a basis for reviewing HFE conformance and effectiveness

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Program plans should include the following:

- Organization of HFE responsibilities
- Choice and relation of HFE activities to be implemented
- Indicated mechanisms for implementation
- Methods to screen and prioritize HFE involvement
- Identification of processes/analyses/products to be credited for regulatory mandates
- Identification of methods for control/maintenance of HFE products
- Mechanisms for processing human engineering discrepancies
- Applicable references

In general, HFE activities should be implemented under dedicated HFE programs or under other formal facility programs. For extensive HFE activities, stand-alone plans should be developed. For smaller jobs, HFE activity planning may be embedded in other engineering procedures or documents. Annex C provides a sample screening checklist such as might be part of an embedded HFE procedure.

6.3 Analysis

Analyses should be developed, maintained, and the results disseminated as necessary throughout facility life. Analytic results should be retained in an accessible, secure, and useful form.

6.3.1 Needs and constraints assessment

Needs and constraints should be assessed in light of operating experience (6.6.3), regulatory requirements, and changing technology. Needs and constraints should be assessed in response to recognized problems, in the development of new systems, or in the significant modification of existing systems.

6.3.2 Functional analysis

Functional analysis/description should be developed for new and existing systems. The analysis and its results should incorporate and be compatible with the role of the user in the system (5.1.1). HFE activities should reflect cognizance of the functions of equipment and systems required to meet the performance objectives of the facility. See also 6.4.4, Allocation of Control Functions.

6.3.3 Task analysis

For significant human interfaces, the detailed activities performed by human users to accomplish necessary tasks should be analyzed, and the requirements for successful task performance should be identified. Such requirements may include inputs to and outputs from the user, their movements, action sequences, decisions, or communications.

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Task analysis should consider the credible range of task demands made by the full range of plant conditions, not just nominal conditions. Task analysis results should show compatibility among:

a) The availability of alarms, displays, and controls;

b) The content of operating procedures;

c) The coverage of user training;

d) The number of qualified staff that are required to be available.

Human actions credited by safety analyses or probabilistic risk assessments for the facility should be subject to formal task analysis. Formal task analysis data for credited human actions should be kept current with the related design, procedures, and training material.

6.3.4 Human reliability analysis

Human reliability analysis should be performed as required by the applicable probabilistic risk assessment or equivalent. See IEEE Std 1082 for additional information on human reliability analysis.

6.3.5 Operator time response analysis

Operator time response should be analyzed where human actions are credited by the facility safety analysis. See ANSI/ANS 58.8 for additional information on operator time response analysis.

6.3.6 Tradeoff analysis

When alternative designs are formally considered, tradeoff studies may be performed to assess the cost-benefits of the competing designs. Human factors implications of the alternative designs should be included in tradeoff analyses. Results from the analyses should be retained as part of the basis for the selected alternative.

6.4 Specification

Specification represents engineering activities and products that relate to the processes of design, development, and implementation. Specifications should provide sufficient detail and constraint to downstream activities so that those activities may be successfully completed. The HFE activities and products identified below should be developed, maintained, and available as necessary throughout facility life.

6.4.1 Design guidelines and conventions

To support design and design change activities, HFE design guidelines and conventions should be formally specified, maintained, and disseminated. These specifications should include facility-specific coding and terminology conventions. Annex D provides a sample design review checklist such as might be used to provide design guidelines to designers. See IEEE Std 1289 for design guidelines for computer-based displays.

6.4.2 Procedures writer’s guidance

Suitable procedure formats are clear to read and to interpret. Conventions and applicable HFE guidance for suitable procedure formats should be specified and controlled as procedure writer’s guidance. Procedure writer’s guidance should be developed and used as part of formal procedure development.

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6.4.3 Design bases

HFE-related specifications (e.g., of design guidelines, requirements, criteria, drawings, procedures, setpoints, algorithms, instruments, displays or controls) should include or be traceable to design basis information. The design basis may consist of rationale, description, references, justification, or other explanatory information that is needed to understand the specified product.

6.4.4 Allocation of control functions

Design documents should include description(s) of the users' roles (5.1.1), and a corresponding basis for the allocation of principal control functions to manual or automatic control. For safety systems, this basis should justify that the system's implementation of manual and automatic control functions is acceptable from safety and regulatory standpoints. The use of manual and automatic controls for safety systems should be in accordance with IEEE Std 603.

6.4.5 Requirements

Requirements should be clearly specified, traceable to sources or bases, and testable. Unnecessary requirements should be avoided. The fulfillment of requirements should be confirmed by appropriate testing or evaluation.

6.4.5.1 Design requirements

Design requirements should include an inventory of display and control capabilities. This inventory should reflect the contents of applicable task analyses and operating procedures, and should include characteristics for each inventory item such as type, range, scale precision, and units of calibration. The specified inventory provides a basis for verifying the availability of the as-built design (6.5.5.1).

6.4.5.2 Procurement requirements

Hardware-related HFE considerations should be incorporated in procurement requirements for equipment hardware.

6.4.5.3 Performance requirements

Performance requirements for the equipment or the integrated system should be included in formal design documentation. Performance requirements should be objective and correspond to testable criteria (either qualitative or quantitative) by which acceptable performance can be confirmed (see 6.5.5.3, Usability validation). Performance requirements should have a clear basis that justifies the imposed criteria.

6.4.5.4 Environmental requirements

Requirements should address environmental considerations so that users are accommodated under all necessary and anticipated conditions.

6.4.6 Implementation

Specification activities and products culminate in an engineering implementation. Implementation activities may include construction, configuration, programming, installation and setup of the system or equipment. Final implementations may be preceded by prototype implementations. Implementation activities typically alternate with appropriate test and evaluation activities to ensure that the delivered implementation will be acceptable.

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6.5 Testing and evaluation

Many types of testing and evaluation are required over the life cycle of a facility. For human factors, testing and evaluation should address various aspects of usability throughout the engineering process, in order to:

- Prove or refine a preliminary design
- Compare two or more alternative designs
- Assess the final acceptability of a design

In general, the usability of a design (e.g., an equipment or a procedure) is tested both by evaluating characteristics of the design itself, and by evaluating the performance of users (individually or in teams) while using the design. For significant human interfaces, usability should be qualified and/or quantified for a representative set of test conditions. Testing and evaluation efforts should be commensurate with the cost-benefits of mitigating human error or of improving human performance associated with the equipment, system, or facility. See IEEE Std 845 for additional information on selecting and applying human performance evaluation techniques.

6.5.1 Measures and criteria

Testing and evaluation measures should be selected, and acceptance criteria should be established and documented, before final testing and evaluation is performed. Criteria should be based on applicable analysis or requirements from approved sources.

6.5.2 Review and comment

Review-and-comment is a table-top evaluation process. It provides a valuable tool for obtaining input, identifying problems, and integrating results across disciplines. Formal review-and-comment processes should be applied at milestone stages of engineering development, and should provide a traceable means to assure that the comments provided have been addressed.

6.5.3 Models, mockups and prototypes

Simplified or preliminary representations of a design or design change should be used for initial testing and evaluation, or for iterative refinement of the design.

6.5.4 Dynamic simulation

High fidelity simulation such as used to train control room personnel should be considered for testing and evaluating any significant human interface that involves complex, interactive tasks. See ANSI/ANS 3.5 for additional information on high-fidelity nuclear power plant simulators.

6.5.5 Acceptability of deliverables

To assure the acceptability of design deliverables, it is necessary to confirm that they satisfy applicable specifications. For significant human interfaces, acceptability confirmation should include the following formal activities. In each case, the reporting of results, the resolution of findings, and the correction of deficiencies should be performed.

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6.5.5.1 Availability verification

The specified content (e.g., alarm, display, and control features) should be confirmed to be available from the as-built deliverable according to applicable design requirements.

6.5.5.2 Suitability verification

The specified format (e.g., characteristics of alarm, display, and control features) should be confirmed to be suitable from the as-built deliverable according to applicable design guidance. Annex D provides a sample design review checklist such as might be used to provide design guidance to reviewers.

6.5.5.3 Usability validation

Usability of the deliverable should be confirmed in a realistic setting with a representative set of tests according to applicable performance requirements. Validation exercises should include users, equipment, and procedures as necessary to assure the acceptable interaction and integration of all elements in the as-built system. Usability of simple systems may be validated by formal pre-operational checks. For complex, unstable, or potentially hazardous systems, a simulator of appropriate fidelity should be used to validate usability under demanding conditions.

6.6 Operations and maintenance

Operations and maintenance (O&M) emphasizes programmatic activities that span much or all of facility life. Existing mechanisms may be used to implement HFE activities, including general mechanisms not limited to HFE, so long as the systematic implementation of HFE is assured.

6.6.1 Configuration and change control

Administrative controls on design characteristics such as coding, terminology, and abbreviations for systems, equipment, and facilities should be maintained. Proposed design changes should consider HFE impact and requirements. Engineering change control processes should include formal confirmation that HFE considerations were addressed. Traceable records of HFE application to significant human interfaces should be maintained. See ANSI/ANS 3.2 for additional information on Administrative Controls and Quality Assurance techniques.

6.6.2 Facility/organizational trends

The performance of the facility/organization should be monitored for human performance trends and for conformance of the results to specified criteria. Significant departures of actual from expected performance should be investigated and corrected, as necessary.

6.6.3 Operating experience review

The review of industry and facility O&M experience for applicable good practices or lessons learned should be performed routinely. Experience should also be reviewed when planning infrequent evolutions, analyzing the root cause of events, or resolving human engineering discrepancies. Results of these activities should be formally disseminated to appropriate personnel so as to benefit facility performance. See IEEE Draft P1586 for additional information on operating experience review.

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6.6.4 Procedure development and maintenance

Procedures should be developed and maintained using a systematic approach that addresses the fundamental considerations presented in 5.5.5 and 5.5.6.

6.6.5 Training and qualification

Requirements for personnel training and qualification should reflect the jobs, tasks, and organization of the facility. Training should be developed and delivered using a systematic approach addressing scope of coverage (5.5.2), development of training materials, and evaluation of results. Operations and maintenance training on a simulator or on the actual system, equipment, or facility should be performed. See ANSI/ANS 3.1 for additional information on techniques for selection, qualification, and training of personnel.

6.6.6 Life cycle changes and decommissioning

Special considerations, including procedure development and training delivery, should be given to prepare personnel for major evolutions or mode changes in facility operations. The fundamental considerations and activities of this Recommended Practice should be considered for decommissioning tasks, as was done for operations and maintenance.

6.6.7 Processing human engineering discrepancies

Human engineering discrepancies in the design may be identified as a result of testing, evaluation, or operating experience (6.6.3). Formal mechanisms such as the plant corrective action program or other tracking system should be used to record, assess and resolve such discrepancies. The process should ensure that resolutions are implemented as planned, also that resolutions are themselves acceptable and not a source of new problems.

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Annex A

(informative)

Bibliography

This brief bibliography is organized by the implementation topics discussed in Clause 6 of IEEE Std 1023-2004. Its citations provide more detailed methods and references, and may be useful for topics other than as given below. It is provided for convenience only, and is not part of this Recommended Practice.

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Annex B

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Sample implementations of HFE activities per the Star Model

One of the guiding principles in IEEE Std 1023-2004 is that there is no single “best way” to implement HFE in the activities of different organizations. Their situations, problems, and approaches normally vary. In response, the Star Model of the engineering process (see 6.1) provides a flexible framework within which varied implementations of the recommended HFE activities are permissible. This Annex presents three examples, all compatible with the Star Model, of how HFE activities could be implemented in different situations.

Figure B.1 presents core HFE functions within the activities of an overall facility organization. In this example, the central role of Operations & Maintenance is represented by its top-most position in the figure. Only general relationships are suggested. Organizational entities that perform these functions, and the relationships between those entities, are matters of practical discretion and are not addressed here.

Figure B.2 presents HFE in the design process of a major system. This example suggests the top-down, “systems approach” to design, beginning with Planning and ending at Operations & Maintenance. The numbered blocks in this diagram often correspond to the scheduled phases of the design process. A single team or group might be responsible for executing the bulk of the process.

Figure B.3 presents HFE in the upgrade process of a major system. In this example, the central role is played by project planning and scheduling. HFE contributions typically will be intermittent and strongly influenced by practical constraints. Embedded procedures (see 6.2) are often used as part of standard work package activities. Diverse groups might be responsible for executing isolated portions of the process.

These examples are provided as potentially useful ways to apply HFE, and also to suggest that other examples are possible. Users of the Recommended Practice are encouraged to integrate HFE activities within their own organizations in the most effective manner possible.

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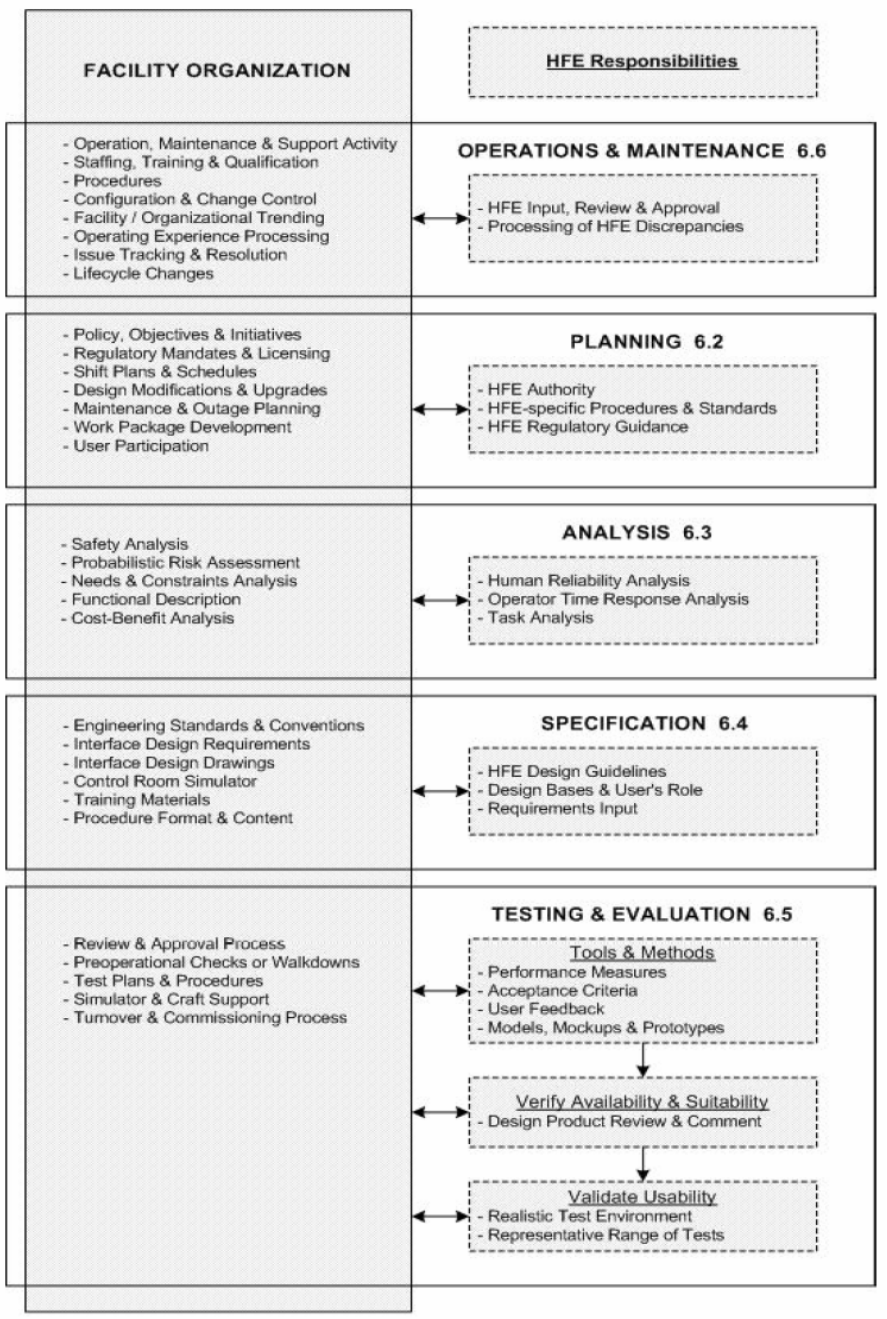


Figure B.1—HFE in facility organization

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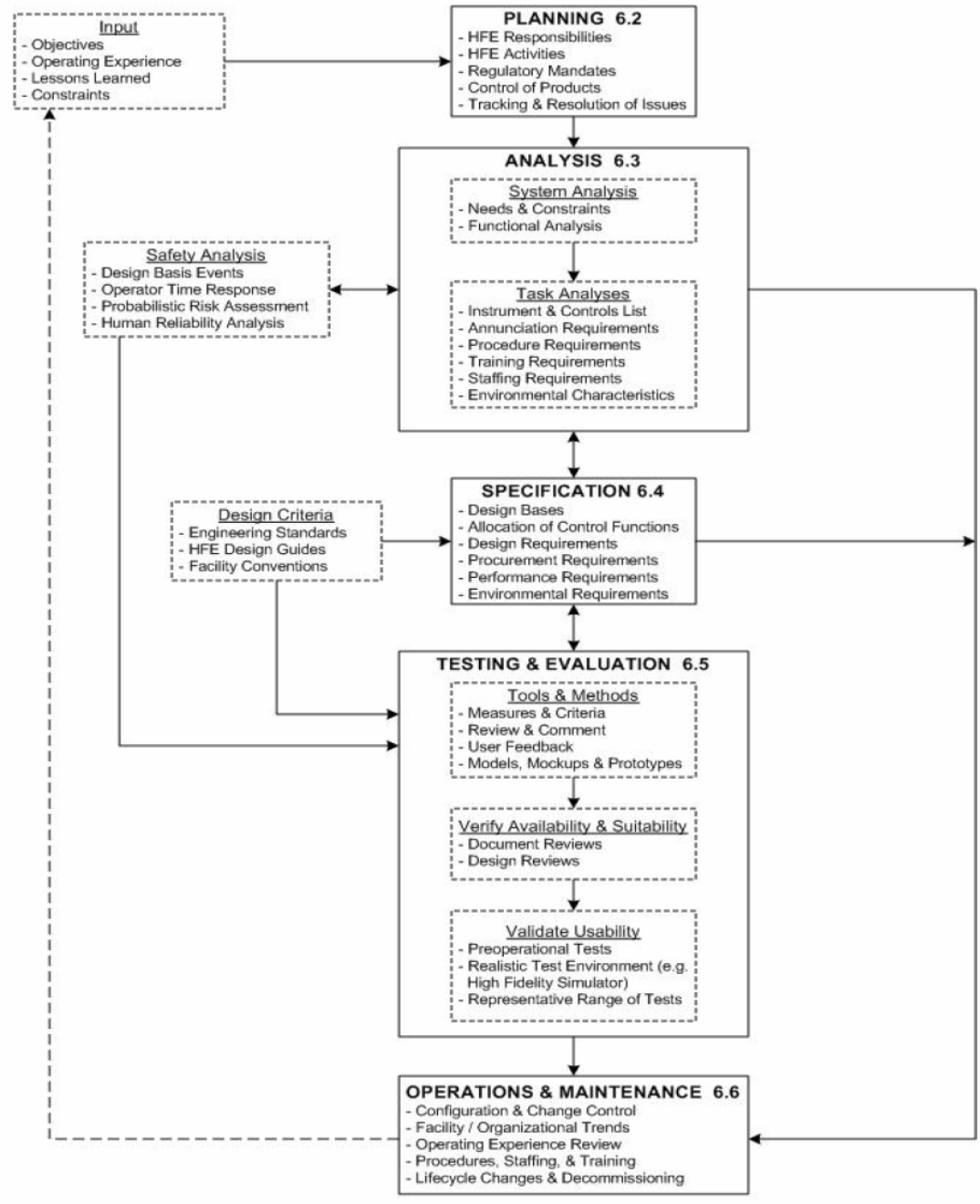


Figure B.2— HFE in design process

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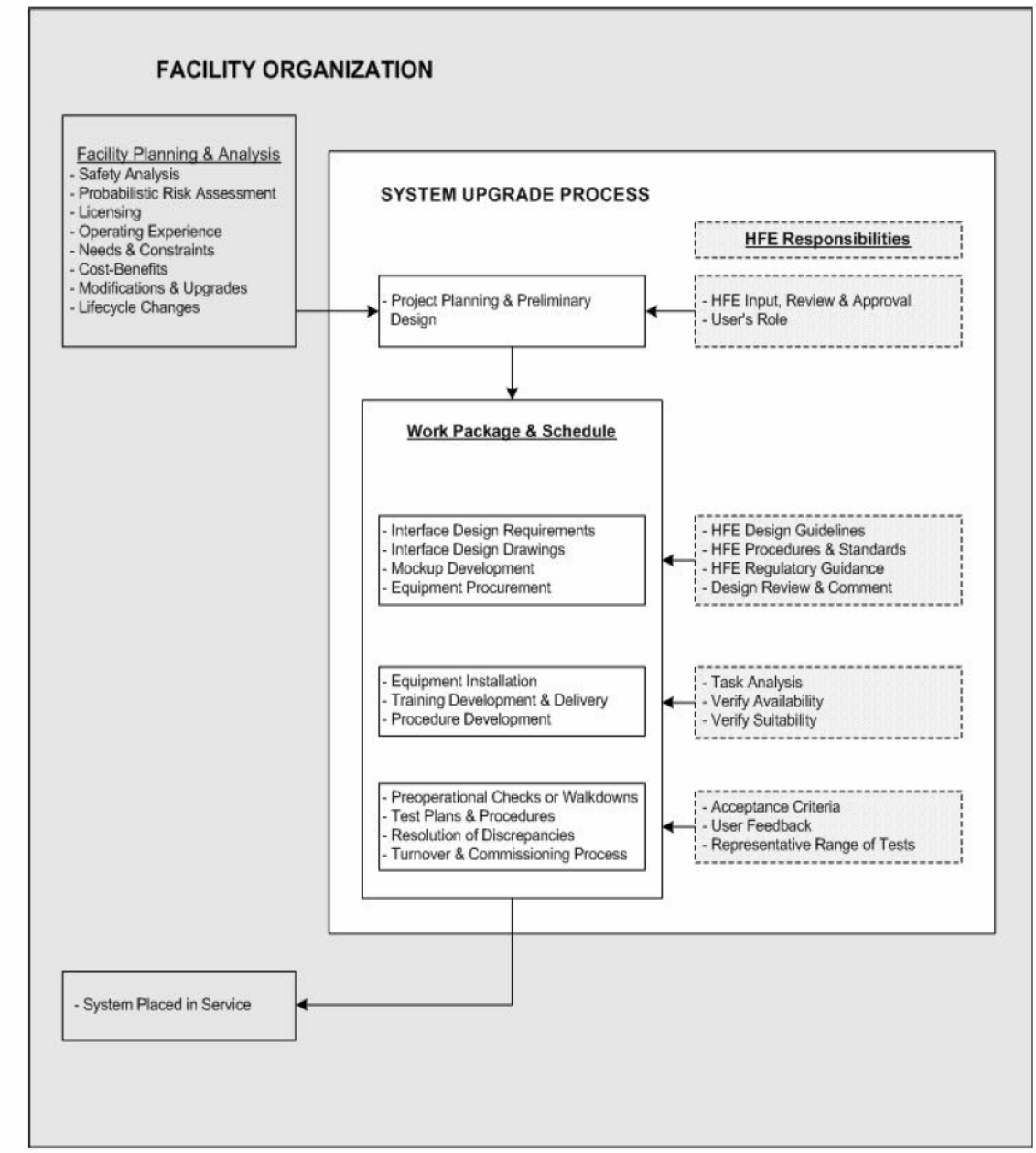


Figure B.3—HFE in system upgrade process

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Annex C

(informative)

Screening checklist

The purpose of the screening checklist is to distinguish between 1) design projects that require little HFE involvement, and 2) design projects that may warrant more extensive HFE involvement. Small or simple projects that require little HFE involvement typically are addressed by application of embedded procedures (see 6.2) and by conformance to applicable design specifications (see 6.4). More complex projects (and all significant human interface projects) require further consideration as to which portions of IEEE Std 1023-2004 are to be applied. This checklist is applicable to both digital and analog equipment.

NOTE—This checklist does *not* distinguish significant human interfaces from other human interfaces. As defined by the Recommended Practice, significant human interfaces are identified by their contribution to facility risk.[8]

To determine whether a design/change warrants further HFE consideration, answer the following questions either YES or NO. If the answers to ALL of the items on the Screening Checklist are NO, then there is no need for further HFE consideration. If the answer to any question is YES, then the cognizant engineering manager should be informed that further HFE consideration is needed.

C.1 Task requirements

1. _____ Will the design changes make it more difficult to perform necessary tasks?
2. _____ Will the design changes affect the logic or dynamics of process operation (e.g., sequence, response time, feedback)?
3. _____ Is there a history of errors or other human factors problems associated with the existing design?

C.2 Control board, panel or rack modification

1. _____ Do the design changes modify the form or function of the user interface (e.g., a component is to be added to the control panel, a component is to be removed and not replaced, components are to be rearranged/configuration is changed)?
2. _____ Will the design changes impact the simulator or training mockup?

[8] Notes in text, tables, and figures are given for information only, and do not contain requirements needed to implement the standard.

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C.3 Component replacements

1. Does the replacement component:
    a) _____ have a different component manufacturer?
    b) _____ have a different model number, regardless of manufacturer?
    c) _____ change the color, look, or style of the item?
    d) _____ change (add, delete, revise) the labeling of the item?
    e) _____ change the location of the item?
    f) _____ change/add/combine component functions?
    g) _____ add/combine several components into one?
    h) _____ impact the simulator or training mockup?
2. Does the replacement component differ from the existing component in any of the following ways:

2.1 Instruments

a) _____ scale graduation mark number, length, width
b) _____ scale overlays: zone banding, units, others
c) _____ color: indicating light (incandescent, LED), bezel, faceplate
d) _____ information: presentation, interpretation, addition/removal
e) _____ chart paper: width, length, graduation marks, numerals or numeric progression
f) _____ range or precision
g) _____ software change involving a user interface

2.2 Controls

a) _____ name plate: type, color, labeling (e.g., nor, norm, normal)
b) _____ addition, deletion or reversal of switch positions
c) _____ type of switch, type of handle (e.g., OT2, SBM, J-handle, thumbswitch)
d) _____ color code of the control switch
e) _____ control/display relationships (direction of movement of indicator pointers versus the direction of control movement)
f) _____ relocation or addition of new control to panel

2.3 Computers

a) _____ a hardware change involving a user interface (e.g., keyboard, mouse, trackball, joy stick, light pen, touch screen)
b) _____ a software change involving a user interface (e.g., database, navigation, display, control, alarm presentation)

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2.4 Annunciators

a) _____ auditory alarm frequency, intensity or sound characteristics (warble, etc.) are changed

b) _____ removal or addition of an annunciator tile

c) _____ any change to an annunciator tile engraving nomenclature or syntax

2.5 Workplaces

a) _____ ambient temperature or humidity is changed

b) _____ ambient noise is changed

c) _____ user access to components is affected

d) _____ visibility of components is affected

e) _____ communication ability or intelligibility is affected

f) _____ the panel color/surface enhancements (mimics line, icons) are changed

g) _____ addition or change to user aids (signs)

h) _____ lighting is changed

i) _____ increase in the potential for cumulative trauma, repetitive strain or musculoskeletal injury (e.g., back, shoulder, arm, hand injury due to lifting, lowering, pushing, pulling, or carrying for long distance)

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Annex D

(informative)

Design review checklist

The purpose of the design review checklist is to direct the attention of designers and reviewers who are not HFE specialists to common sources of HFE discrepancies. While not comprehensive, the checklist is intended to stimulate thought about what could go wrong, and to list common design problems from the HFE point of view. The checklist can be used either as simple design guidance (earlier in the design process; see 6.4.1) or as review criteria (later in the design process; see 6.5.5.2). Problems identified through use of the checklist should be resolved (see 6.6.7).

NOTE—Use of this checklist is *not* a substitute for implementing HFE activities as recommended by IEEE Std 1023-2004.

The Operability section (1.0) of this checklist addresses specific items about the following:

1.1 General HFE considerations

1.2 Instrumentation and control

1.3 Failure modes and effects

The Accessibility section (2.0) of this checklist addresses specific items about the following:

2.1 Location

2.2 Environment

2.3 Tools and Supplies

The Maintainability section (3.0) of this checklist addresses specific items about repair, replacement, and failure.

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Human Factors Engineering Considerations	Yes	No	N/A	Comments
1.0 OPERABILITY				
1.1 General HF Considerations				
a. All handles on cabinets and consoles are recessed, where practical, and are designed to neither injure personnel nor entangle clothing or equipment.				
b. Information and control layouts support human pattern recognition skill.				
c. Display and control layouts represent the actual system layout.				
d. Control room displays are grouped to facilitate user performance.				
e. Systems inform users of important status changes in automatically controlled processes.				
f. All color coding is redundant with some other coding scheme (e.g., shape, size, position, intensity).				
g. The need for users to make hand calculations is minimized, but where necessary, aids are provided (e.g., preprogrammed calculators, nomographs, worksheets).				
h. Procedures show all pre-conditions or actions that must be completed prior to beginning the procedure.				
i. Procedures show all post-conditions or actions that must be confirmed or performed after completion of the procedure (e.g., testing).				
j. Procedures list all precautions, special tools, or special documents necessary to accomplish actions.				
k. High temperature parts and heat sources (e.g., high-current switching devices) are enclosed or shielded.				
l. Internal controls and test points are located away from, or shielded from, high voltage sources.				
m. Each piece of equipment or part is identified by name or common symbol.				
1.2 Instrumentation and Controls				
a. All necessary controls/displays are available to operate the system in the design configuration and in all normal operating modes.				
b. All necessary controls/displays are available to operate the system during off-normal and accident conditions.				
c. Controls/displays are available at convenient locations.				
d. Control functions are allocated to humans or machines on the basis of which is most appropriate to exercise this control.				
e. All manual or supervisory control functions and user interfaces are identified and are clearly defined.				
f. The numbers and types of controls/displays in the design for emergency conditions are compatible with the planned staffing.				

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Human Factors Engineering Considerations	Yes	No	N/A	Comments
g. All necessary information is displayed for operation/recovery in the event of control failure.				
h. For new or upgraded equipment, users are trained on applicable procedures and operating characteristics, with emphasis on significant changes (e.g., from analog to digital).				
1.3 Failure Modes and Effects				
a. Failure modes and effects have been identified for new I&C.				
b. Failure impacts on staffing, training, procedures and skill requirements for users have been determined.				
c. Adequate responses, including alternate means of monitoring and control, are determined for alarm and fault conditions.				
d. Annunciator and alarm systems have been validated for usability and effectiveness.				
e. Emergency and failure mode communications equipment is provided.				
2.0 ACCESSIBILITY				
2.1 Location				
a. Frequently accessed components, adjustments, and test points are easy to find and reach.				
b. Test points, bleed points, and sample points are easy to reach with standard tools without interference or interaction with energized electrical systems, rotating machinery, or high/low temperature lines.				
c. Access points are available for maintenance activities in confined spaces.				
d. Adequate access is available for glove ports and for equipment within glove boxes.				
e. Safe-by-fail parts (e.g., fuses, blow-out plugs) are easily accessed and replaced.				
f. Compartments, tanks, and other confined spaces have two-person ingress/egress capabilities in case of the need for rescue.				
g. Controls (e.g., switches, valve handles) are located so that both the shortest and the tallest users can reach them easily.				
h. Passageways allow free clearance for movement of personnel, parts, and components.				
I. Adequate space is available for personnel to bend or kneel as needed to perform tests and repairs.				
j. Pull-out units (e.g., breakers, racks) can be easily accessed and replaced.				
k. Replaceable or frequently serviced items are positioned to allow access with minimal disassembly or removal of surrounding components.				

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Human Factors Engineering Considerations	Yes	No	N/A	Comments
l. Items/components can be operated or maintained without undue physical strain, awkward body positions, or handgrip/holding methods.				
m. Workstations and associated control/display locations are designed in accordance with accepted HF design practices.				
2.2 Environment				
a. Temperature, humidity and ventilation requirements are defined and met.				
b. Equipment, facilities, and personnel environments are designed to minimize potential hazards to personnel.				
c. Lighting (illumination and luminance) requirements are defined and met.				
d. The lighting system is designed to avoid glare on VDU screens and display surfaces.				
e. Emergency lighting requirements are defined and met.				
f. Nominal ambient noise levels are acceptable for personnel performance and communication.				
g. Expected peak noise levels have been considered and means to protect personnel while permitting adequate communication are provided.				
h. Areas requiring special or protective clothing and equipment are identified.				
I. Potential effects of object and whole body vibrations are identified and minimized.				
2.3 Tools and Supplies				
a. The need for non-standard tools is minimized.				
b. The need for non-standard parts is minimized.				
c. Where needed, non-standard tools and parts are provided.				
d. An adequate inventory of spare parts is readily available.				
e. Uniform bulb and lamp sizes are used wherever possible.				
f. Special equipment required for emergency operations is identified, accessible and pre-staged.				
g. The need for special tools or special equipment is identified by durable labels which are affixed to the tools/equipment.				
3.0 MAINTAINABILITY				
a. Sufficient space exists for use of large tools, hoists, derricks, etc., in repair or replacement of major components.				
b. Pieces and parts are easily distinguishable.				
c. Critical parts and components are designed to prevent incorrect installation (e.g., connectors are clearly differentiated and non-mating for breathing air, nitrogen, and instrument air).				
d. Components can be isolated safely and easily for maintenance.				
e. All points of frequent or periodic maintenance are easily accessible, visible and clearly marked.				

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Human Factors Engineering Considerations	Yes	No	N/A	Comments
f. Access support equipment (e.g., catwalks, platforms) are provided where required.				
g. Access doors or hatches are secured with captive fasteners that require only common hand tools for removal.				
h. Repair access doors or hatches are of sufficient size that all repairable components are easily visible, and repairs can be affected wearing necessary protective clothing and equipment.				
I. Large or heavy items are equipped with ears or lugs for rigging or hoist attachments.				
j. Components that will be run to failure are designed to minimize the adverse effects of their replacement on related components.				
k. Where practical, items/components are designed for in situ maintenance and functional testing.				

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