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Critical Human Factors Issues in Nuclear Power Regulation and a Recommended Comprehensive Human Factors Long-Range Plan

Executive Summary

Prepared by C. O. Hopkins, H. L. Snyder, H. E. Price, R. J. Hornick,
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Human Factors Society, Inc.

Prepared for
U.S. Nuclear Regulatory
Commission

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ABSTRACT

This comprehensive long-range human factors plan for nuclear reactor regulation was developed by a Study Group of the Human Factors Society, Inc. This Study Group was selected by the Executive Council of the Society to provide a balanced, experienced human factors perspective to the applications of human factors scientific and engineering knowledge to nuclear power generation.

The report is presented in three volumes. Volume 1 contains an Executive Summary of the 18-month effort and its conclusions. Volume 2 summarizes all known nuclear-related human factors activities, evaluates these activities wherever adequate information is available, and describes the recommended long-range (10-year) plan for human factors in regulation. Volume 3 elaborates upon each of the human factors issues and areas of recommended human factors involvement contained in the plan, and discusses the logic that led to the recommendations.

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1.0 INTRODUCTION

1.1 Problem

This comprehensive long-range human factors plan for nuclear reactor regulation was developed by a Study Group of the Human Factors Society, Inc. (HFS) for the United States Nuclear Regulatory Commission (NRC).

The contract for the development of the plan is a part of the overall human factors program being pursued by the NRC as a result of the accident which occurred at the Three Mile Island Nuclear Station, Unit 2 on March 28, 1979. The events in the accident sequence included both equipment malfunctions and human errors. Prior to, and during the course of the accident, humans not only failed to make appropriate responses, but also took some actions that exacerbated rather than improved conditions. All of the major investigating groups, both from within the NRC and from outside the organization, concluded that a major cause of the TMI-2 accident was the failure to take human factors into account in the design and operation of the plant. Human factors deficiencies were identified in areas such as human engineering design of the control room, operational procedures, and operator training and qualification.

The TMI-2 unit was not unique in the disregard for human factors in nuclear power plant design and operation. The same kinds of human factors deficiencies existed throughout the industry. Before the accident, there were no human factors organizations or career human factors professionals in any element of the nuclear power community - the NRC, utilities, nuclear steam supply system (NSSS) vendors, architect engineers (AEs), or others. Although the human factors discipline has been an integral part of the scientific and engineering design and development of small and large complex man-machine systems since World War II, it was unknown or ignored in the nuclear power generating community.

1.2 Development of the Human Factors Plan

A series of meetings between NRC and HFS personnel began in late 1979 to explore ways that the NRC might be able to draw upon the experience and expertise of HFS members in the establishment and development of human factors programs. In September 1980, the NRC requested the HFS to submit a proposal for development of a comprehensive long-range human factors plan for nuclear reactor regulation.

The HFS Executive Council deliberated the request and passed the following resolution:

> As a public service of the human factors profession, and consistent with the stated purposes of the Human Factors Society "to promote and advance . . . understanding of the human factors involved in the design, manufacturing, and use of machines, systems, and devices of all kinds," the Executive Council authorizes the preparation of a proposal for "Development of a Comprehensive Human Factors Plan for Nuclear Reactor Regulation . ."

A proposal was prepared and approved in the name of the HFS by the President of the Society, with the concurrence of an advisory committee. A contract was awarded and work on the project began December 15, 1980.

1.2.1 Objective and Scope

The objective was to develop for the NRC a comprehensive human factors plan to cover the next 10 years. The plan is intended to meet the diverse requirements for human factors imposed by the different regulatory functions and responsibilities of the NRC Program Offices and to identify needed programs throughout the NRC. It focuses on those areas concerned with nuclear power plant safety. Nuclear fuel cycle activities such as mining, transportation, and waste disposal are not included. The plan does not address human factors considerations in the areas of plant security or health physics.

1.2.2 Choice of the Human Factors Society to Develop the Plan

The NRC decision to seek help through the medium of the HFS was based upon several considerations. The most significant was that an area of science and technology, previously not utilized, was being introduced into the organizations, programs, and operations of a regulatory agency and the industry it regulates. The development of a comprehensive plan requires an intensive study by qualified human factors personnel of all the different kinds of human activities that are integral to the design and operation of a nuclear power plant. This could not be done by the limited NRC human factors personnel simultaneously with their responsibilities for planning, initiating, and conducting new short-term programs that had resulted directly from the TMI Action Plan (77). The arrangement with the HFS provided the NRC with a wider range of expertise than was likely to be available in a single company or institution. By requiring only part-time availability of individuals over the period of a year, it was possible to obtain the services of qualified, highly experienced, and successful human factors professionals, who would have been inaccessible otherwise.

1.2.3 Project Organization

The Study Group consists of a project manager, a technical director, an agency liaison technical officer, and technical area specialists for human engineering, procedures and operator aids, personnel and staffing, and training and training equipment. The four technical areas include a wide range of human factors concerns. They are not considered to be isolated or independent areas, but are key elements in an overall systems engineering context.

Study Group personnel are:

Project Manager: Harry L. Snyder, Professor of Industrial Engineering and Operations Research, Virginia Polytechnic Institute and State University.

Technical Director: Charles O. Hopkins, Professor of Psychology and of Aeronautical and Astronautical Engineering, University of Illinois.

Agency Liaison Technical Officer: H. E. "Smoke" Price, Executive Vice President, BioTechnology, Inc., Falls Church, Virginia.

Human Engineering: Richard J. Hornick Head, Human Factors and Safety, Hughes Aircraft Company, Fullerton, California.

Procedures and Operator Aids: Robert J. Smillie, U. S. Navy Personnel Research and Development Center, San Diego, California.

Personnel and Staffing: Robert R. Mackie, Vice President, Human Factors Research, Canyon Research Group, Goleta, California.

Training and Training Equipment: Robert C. Sugarman, Director, Human Factors and Training Center, Calspan Corporation, Buffalo, New York.

1.2.4 Project Plan and Method

The project was carried out in two four-month phases and a third six-month phase, referred to as tasks. The requirements of Task A were to determine the aspects of nuclear power plant safety that are related to human factors. This was accomplished through a detailed survey of NRC Program Offices, current reports resulting from investigations of the TMI-2 accident, and other documents and reports relevant to human factors in regulation of design and operation of nuclear reactors. Subject only to the constraints of fulfilling the contractual statement of work, the Study Group's operations were independent of NRC influence.

NRC personnel were helpful and cooperative in response to our requests for information, documents, and meetings. There were no attempts to hinder or discourage our review of any area or to manage our approach to obtaining information from any source.

During Task A, the majority of our activities and contacts were focused upon the NRC. We were given extensive briefings by NRC personnel and we held meetings with individuals and small groups as necessary. At the start of the project, the Study Group attended a special training program provided by the NRC Office of Inspection and Enforcement. This included (1) instruction on nuclear reactor fundamentals and effects of radiation, and (2) one week of operational training and experience on the Browns Ferry control room simulator at the TVA Training Center. During the last month of work on Task A, the Study Group visited the NRC Region 1 Office in King of Prussia, Pennsylvania, for briefings on the responsibilities and operations of that office.

The findings of Task A were expanded, modified, and refined as necessary during Task B as a result of selective meetings and visits with representative elements of the nuclear industry. Sectors of the industry involved in this task were utilities (10); all four NSSS vendors; architects-engineers (3); Department of Energy National Laboratories (2); control room simulator manufacturers/vendors (4); industry sponsored organizations, including the Institute of Nuclear Power Operations (INPO), the Electric Power Research Institute (EPRI), the Nuclear Safety Analysis Center (NSAC), the Edison Electric Institute (EEI), and the Atomic Industrial Forum (AIF); professional societies, including the American Nuclear Society (ANS) and the Institute of Electrical and Electronics Engineers (IEEE); and human factors consulting companies, nuclear industry service companies, and aerospace companies that have worked in the area of nuclear human factors.

The third phase of the project, Task C, was concerned primarily with an evaluation of the regulatory areas and activities that had been identified in terms of a human factors area of concern. Each area of concern was treated in terms of the following factors: the requirement and any technological constraints, an evaluation of the present status of the problem or area of development both within the NRC and in industry, an evaluation of planned activities for the area in the NRC and in industry, identification of missing elements, assessment of technical feasibility and problems, interaction with other system requirements, and recommendations (technical, priorities, schedule, resources, implementation, and interaction). These evaluations comprise Volume 3 of the final report. They are the basis for the recommended comprehensive long-range plan presented in Section 4 of Volume 2 of the final report.

1.3 The Human Factors Discipline

As an aid to readers of this report who may be relatively unfamiliar with the human factors discipline, we have provided, in the introductory section of Volume 2, a selective summary account of human factors. Most of the topics have been selected because of their relevance to the peculiar past and current status of human factors in the nuclear power industry and the perception of the human factors discipline by some individuals in the industry. Topics included in this account are origins and objectives, growth and development, and some fundamental concepts and misconceptions regarding the human factors discipline.

2.0 SYSTEM APPROACH TO HUMAN FACTORS IN NUCLEAR POWER REGULATION

The system approach to incorporating human factors into the life cycle of a man-machine system is a way of ensuring that human factors are adequate, appropriate, timely, and cost-effective.

The system approach recognizes that a design or development decision regarding a particular aspect of the human's interaction with the rest of the system cannot be made in isolation. It almost always has implications for other aspects of man-machine interaction. Although a human operator is a single system element physically, he or she typically performs as an integral part of many different subsystems, equipments, and components. Consideration of the human's potential interaction with all of the system in the light of human capabilities and limitations maximizes the likelihood of designing a system which can be safely and effectively controlled and maintained by humans. The system approach provides a logical, rational sequence of development in which the results of each stage provide the inputs for the next stage. All human factors requirements (displays and controls design, procedures development, training, etc.) are derived from the system-mission requirements in terms of the system functions that are allocated to the human.

Efficient development and safe operation of a man-machine system require explicit attention to human factors from the earliest stages of concept formulation and conceptual design through test and evaluation and operation to decommissioning. Persons unfamiliar with human factors frequently focus upon the design of the control room as the starting point for consideration of human factors. Certainly, in some systems the control room design is the most visible manifestation of the need for human factors. Logically, however, the consideration of human factors cannot begin at this point. The information and control requirements that should determine the design and arrangement of displays and controls must be derived from some more basic considerations than just a designer's whims and ideosyncracies, or the availability of a large supply of meters, dials, or switches manufactured by a division of the company that is responsible for design and construction of the control room. The logical starting point for consideration of human factors is the same as for any other activity important to the design of the system -- the beginning.

We have used a system approach to the identification and evaluation of human factors requirements in nuclear power plant design, operation, and maintenance. Early in the course of our work on this program, we drew upon our individual system analysis, design, and development experiences and jointly developed our concept of an ideal sequence of development of human factors elements in a nuclear power plant. This conceptual model, diagrammed in Figure 1, includes all of the major steps that are required for a system life cycle from preliminary design through development, construction, testing, and evaluation to operation and maintenance. This ideal sequence of development not only delineates sequential dependencies of design requirements and information flow, but also permits identification of interactions among human factors elements and between human factors elements and other parts of the system.

The system approach to incorporating human factors has evolved as part of the design and development process for man-machine systems. Its effectiveness and its value are well established. It is reasonable to question whether the system approach has value for incorporating human factors into systems that have already been designed and constructed. We believe that it does. To be sure, some of the elements of the system approach cannot be applied. Unfortunately, some of the most fundamental elements have already been determined. Nevertheless, even for an after-the-fact analysis of human factors in nuclear power plants, the system approach provides a valuable organizing framework. It also provides a systematic context within which dependencies and interactions can be identified and solutions to problems and deficiences can be developed. Working within the framework of the system approach fosters and enforces the awareness of the ramifications of human factors decisions upon other functions of the system and upon total system performance.

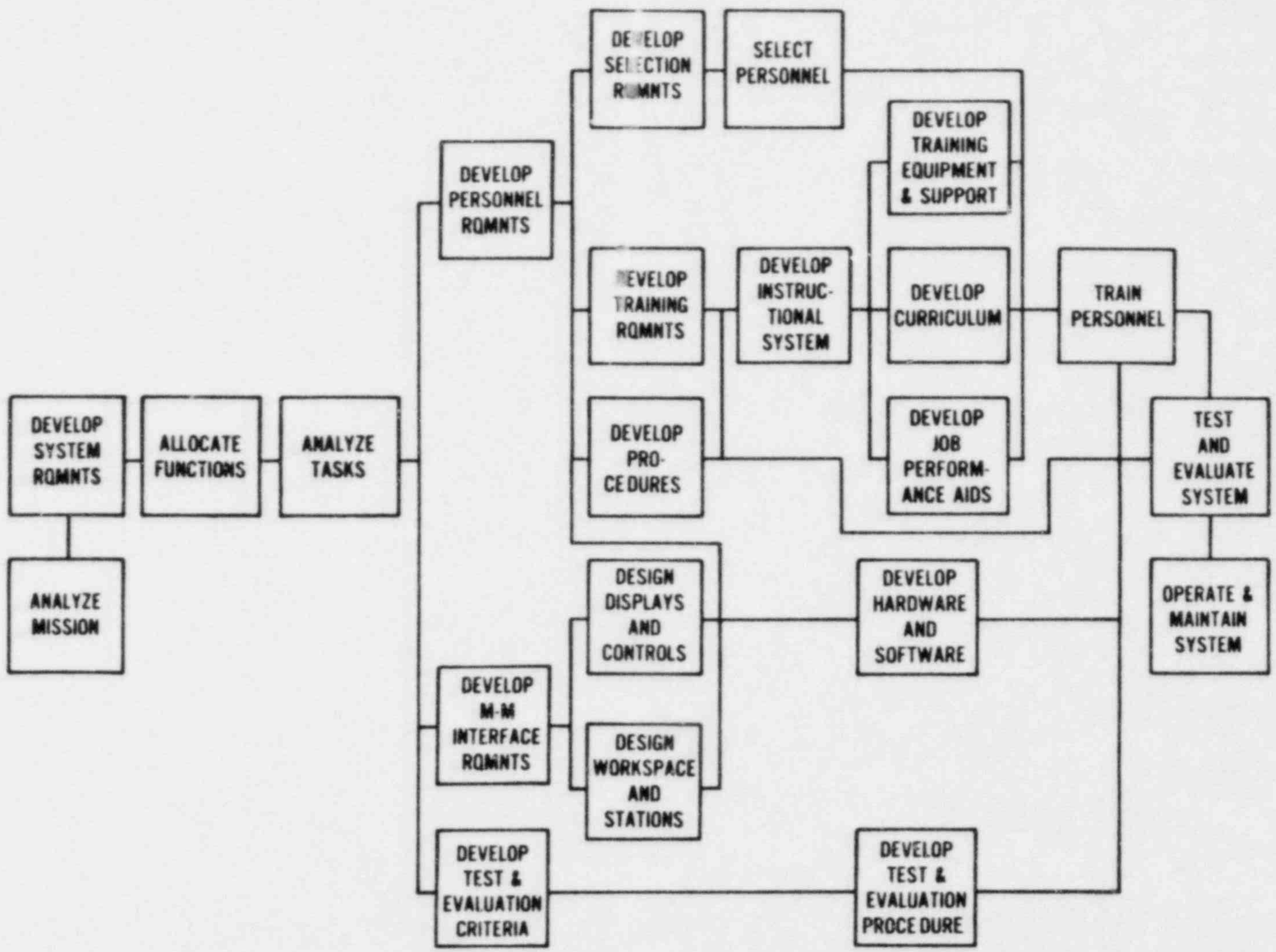

FIGURE 1. IDEAL HUMAN FACTORS SYSTEM APPROACH TO NPP DESIGN.

3.0 HUMAN FACTORS ACTIVITIES IN NUCLEAR POWER

The principle human factors research or development programs and actions are described and evaluated in Section 3.0 of Volume 2. Every attempt was made to be accurate in describing programs and projects. In almost all cases, this was accomplished either by using excerpts from project statements of work or by including descriptive information exactly as it was provided to us by the organization. All major organizations were given rough drafts of the descriptive portions of their activities to review for technical accuracy.

The evaluations are, of course, strictly the assessments of the Study Group. Generally, the evaluations were accomplished in a three-step process. First, products or publications resulting from or related to the program were reviewed. Second, discussions were held with the sponsors and/or the performers. Third, interactive sessions were held among the members of the project Study Group to arrive at a consensus.

Programs were evaluated in terms of (1) the appropriateness of the objective, (2) timeliness, (3) cost/benefit, and (4) quality of work to meet the objective. Because of the large number of individual organizations and programs evaluated it is not feasible to include summaries of separate evaluations in this account. Furthermore, the diversity of programs and the variation in quality of individual programs make general evaluations difficult. To the degree that generalizations can be made, they surely must include the observations that many human factors programs have been ill-conceived, poorly designed and conducted by unqualified personnel, and produced relatively useless results. There are some exceptions. These exceptions are apparent in the evaluations.

Organizations and the number of programs related to human factors that were evaluated are:

NUCLEAR REGULATORY COMMISSION

Office of Nuclear Reactor Regulation

Division of Human Factors Safety

Human Factors Engineering Branch (9)

Procedures and Test Review Branch (2)

Licensee and Qualification Branch (12)

Operator Licensing Branch (1)

Office of Nuclear Regulatory Research

Division of Facility Operation

Human Factors Engineering Research (7)

Personnel, Staffing, and Training Research (8)

Procedures and Operator Aids Research (1)

Risk Analysis and Human Reliability Research (4)

General Human Factors Research (4)

Human Factors Engineering (5)

DEPARTMENT OF ENERGY NATIONAL LABORATORIES

INDUSTRY

Utilities

Industry Sponsored Organizations

Electric Power Research Institute (20)

Institute of Nuclear Power Operations (10)

Nuclear Safety Analysis Center

Edison Electric Institute

Atomic Industrial Forum

Architect Engineers (AEs)

Nuclear Steam Supply System (NSSS) Vendors

Human Factors Consulting Firms

PROFESSIONAL ORGANIZATIONS

Human Factors Society (HFS)

Institute of Electrical and Electronics Engineers (IEEE)

American Nuclear Society (ANS)

4.0 RECOMMENDED COMPREHENSIVE LONG-RANGE HUMAN FACTORS PLAN

4.1 Introduction

The long-range plan consists of recommended courses of action for the areas of human factors concern that were identified, analyzed, and evaluated. The recommendations are organized in terms of the technical requirement, importance, schedule, resources, implementation, and dependencies.

Evaluations of relative importance of technical requirements are based upon composite consideration of system safety needs, programs already in progress or planned, and the judgements of team members based on experience with similar types of problems and requirements in the design and operation of other kinds of complex man-machine systems. One of three levels of relative importance - high, medium, or low - was assigned to each technical requirement. Medium or low should not be interpreted as meaning unimportant. Each technical requirement is important.

Recommended scheduling information is provided in terms of urgency and duration. Four categories of urgency were used to indicate that actions should be started immediately, within one to two years, within three to five years, or within six to ten years. Evaluations of urgency were made separately from evaluations of importance. (Some actions of high importance are of low urgency because they are dependent upon completion of prerequisite actions.) Most of the recommendations that have a high degree of urgency were assigned to the "one- to two-year" start category. A few requirements, including, for the most part, policy decisions, were assigned to the "immediate" category. The Study Group believes they are of such high importance and urgency as to warrant extraordinary management actions to expedite their implementation.

Estimated resources required are stated in terms of person-years. Implementation requirements are special scientific/technical skills and unique facilities and equipment. Dependencies are described for recommended actions that either are contingent upon results from some other program or interact with other system requirements.

Recommendations include requirements for research, technical assistance, regulatory actions, and administrative, organizational, and personnel changes. In many cases the requirements apply specifically to the NRC. These are clear from the nature of the requirements and the wording. Activities to meet the requirements for research may be accomplished by the NRC, contractors, DOE national laboratories, industry, or industry-sponsored organizations. Regardless of the organization performing the research, it is the responsibility of the NRC to ensure that they are accomplished.

4.2 General Human Factors Problem Areas

There are several human factors problem areas that are not directly related to each other in terms of concepts or operations in the way that some problem areas are related and can be grouped under a heading such as human engineering or training. These diverse problem areas typically transcend the other categories.

4.2.1 Professional Human Factors Qualifications in Nuclear Power

The void of qualified human factors personnel in the nuclear industry exposed by the accident at TMI-2 still exists in many organizations and has been filled only partially in most of the others. There are no valid reasons why the NRC and other elements of the nuclear industry cannot employ competent career human factors professionals. This issue is a fundamental one which is related to all other human factors issues in nuclear power generation. It must be considered in the context of meeting all other technical requiremnts included in this plan.

The NRC, utilities, NSSS vendors, and AEs must realistically assess their human factors staffing needs, make a much better effort to understand the meaning of and role of human factors in their organizations, and take the necessary steps to meet that need. This action is of the highest priority in the human factors area. It is not acceptable to annoint a control engineer with the title of "human factors specialist", and assume that the necessary skills can be acquired immediately. Competent career human factors professional staffs must be acquired, placed into suitable organizational positions, and assigned to projects involving man-machine systems. This process should be implemented immediately and continue indefinitely.

4.2.2 The NRC Organization

The NRC, to discharge its responsibility for safety regulation, must have adequate human factors resources to monitor plant design and operations, and to identify, evaluate, and support research in critical human factors areas. Further, the NRC must be organized in a manner in which the required human factors scientific and technical skills can be applied in regulatory, design, operations, and research processes.

The NRC has had some successes in obtaining a very small number of qualified career human factors professionals. In other cases, key human factors positions have been filled with persons without human factors training or experience.

We recommend that, in the Division of Human Factors Safety, the branch chiefs be replaced with career human factors professionals. Either the DHFS Director or Deputy Director must be a senior career human factors professional, and recognized as such by his peers. This career human factors professional should be authorized to have a direct hand in establishing technical policy for the division and in providing technical direction to the branch chiefs.

The organizational visibility of human factors in the Office of Nuclear Regulatory Research should be increased to reflect the importance and magnitude of human factors research activities. Alternative organizational changes are suggested. Regardless of which alternative is followed, the career human factors professional staff should be greatly enlarged to provide the specialized, experienced talent needed to plan, monitor, and understand the diverse human factors research programs. All of these recommended actions are of high importance and should be initiated immediately.

4.2.3 System Integration

Significant system integration during design and development is necessary for the most effective performance of humans in the operation of a large scale, complex man-machine system. The NRC needs to develop a policy and a mechanism for ensuring effective system integration during the design and development of new nuclear power plants in the event that any more should ever be proposed. Human factors, as well as other major functional subsystems, should be included in the system integration process.

Specifically, the NRC should establish a system integration organization to determine policy and procedures for the NRC to use in ensuring effective system integration in any future plant design and development. The importance of this action is high, but the urgency is low, unless there is a change in the prospects for new construction permits. We estimate that the policy formulation should require a year, but the organization should continue in existence to oversee implementation. The members of the organization should be drawn from the NRC staff and should include legal personnel as well as technical representatives of major subsystems, including human factors. The head of the organization should be a career system engineering professional.

4.2.4 Safety Related Equipment Classification

The reactor operator is an important functional part of both safety grade and non-safety grade subsystems. When there is a requirement for time sharing of responses by the operator among subsystems, the distinction between the two classifications is not useful. It may be detrimental if this distinction results in inferior human engineering design of displays and controls for the non-safety grade subsystems or if it results in development of procedures for these subsystems that are incomplete, confusing, or difficult to use.

It is technically feasible to adopt a policy that requires all design and development of the man-machine interface to be done on the basis of system requirements and accepted human factors principles and practice. The NRC should either adopt a new approach to the issue of safety qualification of equipment or classify all elements of the man-machine interface as safety related. In the event the latter alternative is selected, the NRC should determine the system interactions and effects of such action and implement any necessary guidelines and regulations. This action is of high importance and should be initiated immediately. We estimate that the study will require four person-years plus NRC staff and should require one year to complete. The resources required are a career human factors professional, and I & C engineer, and a nuclear systems engineer.

4.2.5 Analysis and Evaluation of Operational Data

Methods for systematically collecting data on plant operations are necessary to detect design and operating difficulties with safety implications. The event reporting systems that the NRC has been using for many years were not designed and cannot be used in a manner to provide useful data concerning human factors.

The NRC should establish a program to define the existing and projected long-term human performance data requirements for various functions within the NRC and utilities. The requirements should be matched with existing data systems and any unmet needs should be identified. Methods should be designed for fulfilling the data collection, processing, and dissemination requirements and a program should be established to complete the development and implementation. This action is of high importance and should be initiated within one to two years. We estimate it will require two person-years of professional resources and will require a year to complete. The task will require the services of a behavioral scientst and a computer data management specialist.

4.2.6 The Human's Role in Increasingly Automated Systems

Even after many years of NASA, DOD, and aerospace industry experience with manual, semi-automatic, and highly automatic systems, there is no solid evidence to suggest an ideal level of automation in the control of complex systems. The human element cannot be eliminated entirely and the mix of human and computerized control is highly mission, system, and cost dependent. Nevertheless, enough is presently known about human capabilities and limitations to develop a method and criteria for the allocation of functions early in system design to determine an optimal role for the human in a specific system design.

The Study Group does not believe it appropriate to suggest a major research program in this area. There are indications that some European work eventually may shed some light on the problem. We suggest that the NRC continue to monitor that work and maintain a modest effort on developing criteria for function allocation. The level of effort should be two person-years per year for three years. The urgency is low.

4.2.7 Risk Analysis and Human Reliability

The programs that have attempted to obtain human error probabilities (HEPs) have met with only limited success. Improvement of this deficiency would be tremendously expensive, and validation of the resulting HEPs is, while theoretically possible, practically infeasible. While the human reliability estimation process is reasonable and logical for a well trained analyst, the process seduces the user into believing that resultant probability values are valid, in spite of the nonvalidated input HEPs. The present state (and predicted future state of NPP design and modification) disregards good system engineering/system integration concepts, and therefore, cannot make design use of HEPs. If proven system design techniques associated with human engineering of workstations, personnel selection, operator procedures and aids, and training systems are applied to NPP operations and maintenance, then HEPs will be minimized and human operator performance will be maximized. Under these circumstances, no further improvements are likely and predictions resulting from HEPs become superfluous, even if generated from an improved, valid human error data base. (The potential argument that probabilistic risk assessment (PRA) might distinguish between the relative merits of two different designs, each based upon the same proven human factors design techniques, is fallacious, for the PRA/HEP data will always be less valid, or more "noisy" than will tried and proven design concepts based upon empirical performance data.) This is not to say that PRAs are useless, for precisely the opposite is true. Rather, we suggest that PRAs which are heavily driven by invalid HEP data may produce spurious results.

Accordingly, it is recommended that the current high level of research in HEPs be reduced to only an awareness of performance measurement activities. The NRC should also maintain awareness of other tasks that might provide useful, empirical data on HEPs and attempt to shape those tasks, where feasible, such that valid HEP data can be obtained at no significant additional cost or effort. This can be an NRC staff (RES) function and requires no substantial resources.

4.2.8 Evaluation Criteria

Possibly the most general requirement related to attempts by the NRC and the nuclear power industry to improve safety and efficiency of power plant operations is the need to develop objective evaluative criteria for use in validating changes. This is equally true whether the need is to evaluate control room "enhancements", operator examination standards, improvements in training programs, specification of simulator features, assessment of operating and maintenance procedures, improvement in personnel selection, or recommended work/rest cycles. What is lacking in all these instances are objective measures (criteria) of effectiveness against which to validate the presumed system improvements.

Research should be conducted to identify objective performance criteria. To the extent possible, the criterion measures should reflect performance on a representative subset of the universe of actual operational tasks. The feasibility of defining a common set of performance criteria based on this subset of tasks that will serve a diversity of evaluation needs should be determined.

The practicality, cost, and technical feasibility of employing unobtrusive data collection methods relating to the evaluative criteria should be determined for operating plants, full-scale simulators, and part-task simulators.

Research should be conducted to define useful secondary criteria such as progress through training, licensing examination scores, supervisory ratings on various dimensions of performance, frequency of involvement in "events", or critical incidents, and turnover rate.

Research should be directed toward the development of a comprehensive criterion of performance effectiveness for operator and maintenance personnel. This criterion should reflect not only technical competence but also other job relevant considerations such as performance under stress.

The importance of the technical requirement for evaluation criteria is high. An immediate start is necessary for the evaluative criteria that will be required for evaluating near-term changes or developments. The more general research program should be initiated within the next one to two years. The program is estimated to require three to five years. The resources required are five professional person-years per year, access to control rooms, and unrestricted use of simulators. The professional personnel should represent expertise in human performance measurement, statistical methodology, plant operations, plant maintenance, and application of computers to performance measurement. Completion of an operator task analysis is a desirable but non-essential prerequisite to initiating the research.

4.2.9 System Engineering of the Regulatory Requirements

The NRC has issued many new requirements since TMI-2 that impact human factors. Many existing requirements have been updated and reissued to reflect new policy. The NRC should issue a clarification as soon as possible which will integrate the individual activities of these major efforts and will account for the dependency, conflicts, and compliance dates. Such a clarification would not only strengthen the end results but would also tend to reduce the variance and methods of approach and levels of effort contemplated by the utilities. It should be noted that the DEDROGR of the NRC has recently made this attempt (151), but this Study Group has severe disagreements with the content and emphasis of that document. See Section 3.1.1 of Volume 2 for a discussion of this issue.

We assign high importance to this requirement and recommend that it be initiated immediately. It should require no more than three months, including publication. The only resources required are NRC staff.

The recommended schedule and estimates of staffing for the technical requirements for the general human factors problem areas are summarized in Figure 1. The last column of Figure 1 codes each recommended requirement by importance: high (H), medium (M), or low (L).

PROBLEM AREA AND TECHNICAL REQUIREMENT	START TIME, DURATION, AND PERSONNEL REQUIREMENT										
	1	2	3	4	5	6	7	8	9	10	
4.2.1 PROFESSIONAL HUMAN FACTORS QUALIFICATIONS IN NUCLEAR POWER											
● NRC AND INDUSTRY REALISTICALLY ASSESS AND MEET HUMAN FACTORS NEEDS	IMMEDIATELY										H
4.2.2 NRC ORGANIZATION											
● APPOINT CAREER HUMAN FACTORS PROFESSIONALS DHFS BRANCH CHIEFS	IMMEDIATELY										H
● APPOINT SENIOR HUMAN FACTORS PROFESSIONAL DHFS DIRECTOR OR DEPUTY	IMMEDIATELY										H
● ELEVATE RES HF ORGANIZATION TO DIVISION OR BRANCH STATUS	IMMEDIATELY										H
4.2.3 SYSTEM INTEGRATION											
● ESTABLISH NRC SYSTEM INTEGRATION ORGANIZATION								STAFF			H
4.2.4 SAFETY RELATED SYSTEM CLASSIFICATION											
● DETERMINE EFFECTS OF CLASSIFYING MAN-MACHINE INTERFACE SAFETY-RELATED	4										H
4.2.5 ANALYSIS AND EVALUATION OF OPERATIONAL DATA											
● ESTABLISH HUMAN PERFORMANCE DATA ACQUISITION REQUIREMENTS		2									
4.2.6 HUMAN'S ROLE IN INCREASINGLY AUTOMATED SYSTEMS											
● MONITOR HALDEN AND OTHER RELATED WORK						STAFF					L
● CONTINUE FUNCTION ALLOCATION CRITERIA RESEARCH	2	2	2								L
4.2.7 RISK ANALYSIS AND HUMAN RELIABILITY											
● REDUCE LEVEL OF RESEARCH. OBTAIN EMPIRICAL DATA FROM OTHER TASKS.						STAFF					L
4.2.8 EVALUATION CRITERIA											
● RESEARCH ON OBJECTIVE PERFORMANCE CRITERIA	2	5	5	5	5	5					H
4.2.9 SYSTEM ENGINEERING OF REGULATORY REQUIREMENTS											
● INTEGRATE AND CLARIFY H.F. REQUIREMENTS AND GUIDELINES	IMMEDIATELY – PUBLISH WITHIN 3 MONTHS										H

Note: Numerical entries are person-years per year.

FIGURE 2. SCHEDULE FOR MEETING TECHNICAL REQUIREMENTS IN GENERAL PROBLEM AREAS

4.3 Human Engineering Problem Areas

The failure to use human engineering design in nuclear power plants is well documented. On the basis of our study of these documents, and our intensive contacts with utilities, NSSS vendors, AEs, and others, we have identified specific issues that require attention.

4.3.1 Design Induced Error

Human error in the operation and maintenance of nuclear power plants frequently is the result of improper design and arrangement of controls and displays. Certain designs lead almost invariably to misinterpretation, failure to respond, or incorrect response. There are no unusual constraints that would prevent sound human engineering design of control rooms for plants currently being designed and built. There are some constraints that make complete conformance to established human engineering design criteria infeasible for currently operating plants. Much, however, can be done to eliminate or reduce the probability of design induced error even in these plants.

The intent of all major provisions of NUREG-0700 (81) should be implemented as requirements rather than as guidelines. NRC should review license applicants not only in accord with NUREG-0700 and NUREG-0801 (87) but also in accord with the recommendations of EPRI-NP-1118 (33). A document for human engineering similar to NUREG-0700, but relative to plant maintenance features, should be published. These actions have high importance and should be initiated immediately. The program could be carried out by NRC staff personnel and should be completed within two years.

NRC should produce a guideline document which requires license applicants to achieve designs of emergency shutdown panels with controls, displays, and their arrangements as similar as possible to those in the control room used for the same required functions. We believe this to be of medium importance and the project should be initiated within three to five years. The NRC staff should be able to complete the document within a year, and an additional year might be required for utility implementation.

Local control stations, such as those used for radiation waste functions, should be equipped with controls and displays that meet the human engineering design criteria of NUREG-0700. The NRC staff should produce a guideline document for this purpose. This medium importance action should start within three to five years and require two years for complete implementation.

A serious study of the use of color coding, especially the use of red and green, and an experimental investigation of the "green board" concept should be conducted. The importance of this work is judged to be medium. It should start within the next six to ten years and require three to four years to complete. Resources required are 30 to 40 person-years, including career human factors professionals and behavioral/statistical analysts, a reconfigurable simulator, software, a laboratory, and test subjects.

The NRC should continue research and development on advanced display technologies such as that work currently being performed by Lawrence Livermore and Idaho National Engineering Laboratories. This medium importance work should require two to three person-years per year over a two-year period.

4.3.2 Inconsistent Control Room and Plant Design

The reality of large differences in control room design is dramatic, not only among utilities, but within the same utility for the same type of reactor. It is unrealistic (and in special cases, undesirable) to expect full consistency. It is important to assess the human engineering factors regarding consistency. Certainly, there are broad human factors considerations relative to manning, transfer of training, personnel practices, and the like. But, strictly from a human engineering viewpoint, the question is not whether designs are identical, but whether the specific features are error-inducing in themselves. The reasons for a wide variation in control room and plant designs were identified as a failure to use a systems approach to design and lack of specific standards from the NRC. In the event that there are indications of a reversal of the current trend in construction of nuclear power plants, the NRC should initiate a program to ensure that standards and specifications relating to good human engineering practice are followed.

4.3.3 Annunciators and Alarms

A control room may contain 1000 to 2000 annunciators. There have been no standards for their design. Consequently, there are problems including lack of priority heirarchy logic, inconsistency of color coding, variability of legend terminology, variability of flash rates, and variance of schemes for alarm acknowledgement. Similar types of problems exist with auditory alarms.

The NRC should initiate rulemaking activity to require adherence to Section 6.3 of NUREG-0700 for existing annunciator systems. Utilities should analyze the systems and identify changes which can be made toward compliance in order to enhance their effectiveness. This highly important action should be started immediately and should be completed within two years. No resources other than NRC staff are required.

Within the next one to two years, a one-year study should be conducted to extend the work reported in NUREG/CR-2147 (109). The product should be a standard or specification for annunciators dealing with acknowledgement/silencing features, location, color coding, etc. This is considered to be of high importance and would require the services of a career human factors professional.

The NRC should encourage industry studies to determine the requirements for development of logic systems aimed at filtering or restricting alarms. These studies should be structured with a systems approach to include consideration of operator information requirements. The NRC should also sponsor studies and then issue an alarm requirements document for advanced control rooms using CRTs and computer-generated displays. This high importance work should begin within three to five years and require three years to complete. Resources of 12 to 15 person-years should include an experienced nuclear engineer and career human factors professionals. Other requirements are laboratory and computer facilities, flexible programming, systems modeling, and test subject.

Highly important research in the area of system status verification guidelines should be continued and expanded. We recommend that four person-years and six-person years be devoted to the first and second years, respectively, of this research.

4.3.4 Design for Maintainability

The emphasis of NRC research in the human factors maintenance area should be shifted from error models and risk assessment to design analysis. A guideline document, similar to NUREG-0700, that defines human engineering design criteria for maintenance, should be developed. This high importance project should be started within one to two years and should be completed within a year.

Empirical and analytical studies on development of better protective garments and better tools and instruments for use in a radioactive environment should be started within the next three to five years. These medium importance studies should require a total of nine person-years over a three-year period. Implementation will require personnel experienced in biomechanics, environmental physiology, biochemistry, and human factors.

4.3.5 Design Freeze

Analyses should be performed to determine the relative merits of using a "design freeze" process vs. the currently used "racheting" process for design of power plants. This is considered to be of high importance and should start within one to two years. It should be accomplished by the NRC staff over a period of one to two years.

The recommended schedule and estimates of staffing for the technical requirements in the area of human engineering are summarized in Figure 3.

4.4 Problems in Procedures and Operator Aids

Problems in the areas of nuclear power plant control room procedures and operator aids cover a wide range from the necessity for establishing standards and specifications for procedures development to development of procedures and systems for performance verification.

4.4.1 Standards and Specifications Governing Procedures Development

The NRC should assume responsibility for the development of non-plant-specific specifications for procedure development that meet the requirements of 10 CFR 50. This should be undertaken within the next one to two years and continue for three years. In addition to the work done by professional societies, the NRC should be able to complete the task as a staff function. NRC staff participants should include career human factors professionals with backgrounds in technical data development and presentation techniques.

4.4.2 Procedure Development Process

Each utility should be required to develop specific guidelines for normal and emergency operating, maintenance, and administrative procedures. These should then be reviewed by the NRC for compliance, using the non-plant-specific specifications for comparisons. This work is considered to be of high importance but cannot begin for three to five years since it is dependent upon generation of the non-plant-specific specifications. It should be completed in one year and require two-person years per utility and an additional person-year of NRC staff time.

PROBLEM AREA AND TECHNICAL REQUIREMENT	START TIME, DURATION, AND PERSONNEL REQUIREMENT										
	1	2	3	4	5	6	7	8	9	10	
4.3.1 DESIGN INDUCED ERROR											
● IMPLEMENT 0700 AS REQUIREMENT	IMMEDIATELY										H
● DEVELOP HE MAINTAINABILITY GUIDELINES		STAFF									H
● DEVELOP HE GUIDELINES FOR EMERGENCY SHUTDOWN PANELS											M
NRC DEVELOP				STAFF							
UTILITIES IMPLEMENT					STAFF						
● DEVELOP HE GUIDELINES FOR LOCAL CONTROL PANELS											M
NRC DEVELOP				STAFF							
UTILITIES IMPLEMENT					STAFF						
● RESEARCH ON COLOR CODING AND GREENBOARD CONCEPT						10	10	10	10		M
● CONTINUE RESEARCH ON ADVANCED DISPLAY TECH.		2	3								M
4.3.2 INCONSISTENT CONTROL ROOM & PLANT DESIGN											
● ENCOURAGE ADVANCED DESIGN MODULARITY AND SOFTWARE FLEXIBILITY		CONTINUING									L
4.3.3 ANNUNCIATORS AND ALARMS											
● INITIATE RULEMAKING TO REQUIRE SECTION 6.3 OF NUREG-0700											H
RULEMAKING	STAFF										
INDUSTRY COMPLIANCE		STAFF									
● EXTEND TYPE OF RESEARCH REPORTED IN NUREG/CR-2147		1									H
● DESIGN LOGIC SYSTEM FOR FILTERING/RESTRICTION OF ALARMS				5	5	5					H
● CONTINUE & EXPAND RESEARCH ON SYSTEM STATUS VERIFICATION		4	6								H
4.3.4 DESIGN FOR MAINTAINABILITY											H
● SHIFT EMPHASIS FROM ERROR MODEL/RISK ASSESSMENT TO DESIGN ANALYSIS											
● DEVELOP HE DESIGN CRITERIA FOR MAINTENANCE GUIDELINES		STAFF									M
● RESEARCH ON PROTECTIVE GARMENTS AND TOOLS FOR MAINTENANCE				3	3	3					M
4.3.5 DESIGN FREEZE											H
● STUDY AND EVALUATE MERIT OF DESIGN FREEZE PROCESS		STAFF									

FIGURE 3. SCHEDULE FOR MEETING TECHNICAL REQUIREMENTS IN HUMAN ENGINEERING

4.4.3 Job Performance Aids

The requirements for hard copy, electronic, and computer-based job performance aids need to be established for both control room and maintenance personnel. This task, which is dependent upon completion of NRC and INPO job/task analyses and implementation of the provisions of NUREG-0700, can start in about three to five years. It should require two years to complete but the level of effort cannot yet be determined. Personnel required will include career human factors professionals, system analysts, and subject matter experts.

4.4.4 Formats for Procedures and Job Performance Aids

The existing formats of procedures and job performance aids should be reviewed for applicability. Studies should determine (1) alternative choices for information presentation techniques, (2) format limitations of CRT and other computer-based displays, and (3) feasibility of using CRTs for the presentation of procedures. Guidelines should be developed for acceptable JPA formats. The research, which is of high importance, should start in one to two years and require three years to complete. Required resources are 10 to 12 person-years with access to computer-driven CRTs, part-task and whole-task simulators, and mathematical models of reactor systems. Necessary personnel will include career human factors professionals, system analysts, programmers, graphics illustrators, and subject matter experts.

4.4.5 Procedure Implementation and Revision

An effective process for implementing and revising operational and maintenance procedures needs to be developed. This should include requirements for an information management system that will (1) index and cross-index all plant procedures to ensure timely and appropriate incorporation of changes, and (2) track procedures to ensure that they are distributed and recalled in a timely manner and to ensure that operational feedback from within and outside the plant are incorporated into procedure revision when necessary. This requirement is relatively low in importance. It should be initiated within six to ten years and require one to two person-years over a period of one year. Personnel skills include an information management specialist and a career human factors professional.

4.4.6 Performance Veri' cation

Performance ve..fication is necessary to ensure that critical tasks and safet, procedures are performed correctly. We recommend that the NRC study the development of a reliable automatic system atus monitoring device that will provide information on (1) valve and switch positioning upon completion of surveillance, test, calibration, and standard maintenance tasks, (2) completeness of tag-out procedures including removal upon task completion, and (3) inadvertant violation of the technical specifications. This program of medium importance should start in six to ten years. One year should be required to develop the basic system, but work should continue as long as reliability can continue to be improved significantly. Resources required are five person-years of personnel time, including career human factors professionals, system analysts, programmers, nuclear engineers, and knowledgable plant personnel.

4.4.7 Change of Shift Procedures

The NRC considers the recommendations of Task Action Plan Item I.C.2 to have been completed. The lack of a standard or specification detailing what is required and the format and content of checklists has resulted in inconsistencies in level of detail. All the necessary ingredients for ensuring adequate change-of-shift procedures are available. However, compilation, integration, and application of them are lacking. NRC should establish criteria for effective change-of-shift procedures, and develop requirements for checklists and procedures such as walk-throughs and log reviews by both operational and maintenance personnel. This action is of high importance. It should be initiated within one to two years and be completed within one year. It could be an NRC staff function requiring the services of a career human factors professional and a nuclear engineer.

A recommended schedule and estimates of staffing for the technical requirements in the area of procedures and operator aids are summarized in Figure 4.

4.5 Personnel and Staffing Problems

Personnel and staffing demands are driven by the requirements of safety standards, operational quality assurance, maintenance effectiveness, and effective management for normal, off-normal, and emergency conditions. In addition to extensive interaction with plant design and personnel training, the personnel and staffing area is impacted by selection criteria, operator qualification and requalification standards, examining procedures, shift duration and rotation practices, performance

PROBLEM AREA AND TECHNICAL REQUIREMENT	START TIME, DURATION, AND PERSONNEL REQUIREMENT										
	1	2	3	4	5	6	7	8	9	10	
4.4.1 STANDARDS & SPECIFICATIONS GOVERNING PROCEDURE DEVELOPMENT											
● DEVELOP SPECIFICATIONS FOR PROCEDURE DEVELOPMENT			STAFF								H
4.4.2 PROCEDURE DEVELOPMENT PROCESS											
● REVIEW UTILITY-DEVELOPED GUIDELINES FOR PROCEDURES				STAFF							H
4.4.3 JOB PERFORMANCE AIDS											
● ESTABLISH REQUIREMENTS FOR HARD COPY, ELECTRONIC, AND COMPUTER JPAs				TBD	TBD						M
4.4.4 FORMATS FOR PROCEDURES AND JOB PERFORMANCE AIDS											
● DEVELOP GUIDELINES FOR JPA FORMATS, VALIDATION AND IMPLEMENTATION		4	4	4							H
4.4.5 PROCEDURE IMPLEMENTATION AND REVISION											
● DEVELOP EFFECTIVE PROCESS FOR IMPLEMENTING AND REVISING PROCEDURES						2					L
4.4.6 PERFORMANCE VERIFICATION											
● DEVELOP AUTOMATIC SYSTEM STATUS MONITORING						5					M
4.4.7 CHANGE OF SHIFT PROCEDURES											
● ESTABLISH CRITERIA FOR CHANGE OF SHIFT PROCEDURES		1									H

FIGURE 4. SCHEDULE FOR MEETING REQUIREMENTS FOR PROCEDURES AND OPERATOR AIDS

assessment and feedback practices, and a variety of factors that constitute the reward system.

4.5.1 Personnel Selection - Practices and Standards

Research should be conducted leading to the validation of current and proposed selection procedures against comprehensive criteria of the job effectiveness of plant personnel. The validation should reflect both technical performance and secondary criteria such as trainability and probability of meeting NRC qualifications for licensing. This is a high importance item that should start immediately, using currently available criterion measures. It should be a continuing program to make use of refinements in criterion measures and new developments in selection technology. Its implementation requires a professional psychologist with experience in industrial or military personnel selection. This person must have access to data reflecting various criterion measures.

Research should be conducted to determine and predict the abilities of NPP personnel to react appropriately to accident-induced stress. Methods need to be developed to select individuals with high emotional stability. This high importance task should begin in one to two years and will require three to four person-years per year for two years. Personnel working on this task should include a research psychologist and a stress psychologist. A dedicated simulator and physiological measurement capabilities may also be required.

The NRC should monitor and critically evaluate behavioral reliability programs initiated by industry, including benefits, evidence of validity/payoff, and potential deficiencies/abuses. We consider this requirement to be of medium importance. The activity should begin upon the initiation of behavioral reliability programs and continue until the benefits, if any, of the program are clearly established. Resources required are NRC staff time, plus consultants at the rate of one half person-year per year. Consultants should be qualified industrial psychologists.

Research should be conducted on new technology testing procedures in an attempt to predict variance in personnel effectiveness criteria that is not well predicted by presently available aptitude and temperament tests. This is a low importance task that could begin within six to ten years. It would be a continuing program requiring two person-years per year. Implementation requires qualified measurement psychologists and a technology specialist in computerized testing.

4.5.2 Operator Certification and Licensing

There is a requirement for conducting research aimed at the development of objective performance standards for operational and maintenance personnel. Methods should be developed for routinely evaluating all major dimensions of the job performance of ROs, SROs, and Shift Supervisors. Studies are necessary to identify and define those dimensions. This high importance research should start within one to two years and require three years to complete. Resources required are three person-years per year by career human factors professionals with unrestricted use of simulators and access to operating plants.

It is highly important to conduct research with the objective of developing more specific qualification requirements for currently non-licensed personnel who are in a position to directly or indirectly impact plant safety. This research should start within one to two years. The research will require two years and five person-years per year. Implementation requires career human factors professionals and engineers familiar with plant design and maintenance requirements.

A low importance research project should be initiated within six to ten years to develop methods for assessing and tracking progress through in-plant training programs. The objective is to improve the certification process for license candidates. This should be a one-year project and require the resources of a training specialist and a computer programmer.

Research of medium importance that should be started within one to two years is required to define objectively the scope and length of "experience" required prior to qualification of ROs, SROs, and Shift Supervisors, and to provide a defensible basis for trading formal education against "experience". The research should require two-and-a-half person-years per year for two years. Implementation requires a career human factors professional and power plant subject matter experts.

4.5.3 Staffing and Organizational Characteristics

Research should be aimed at development of criteria whereby the effects of staffing and organizational variables can be objectively assessed. This should consider not only performance measures but secondary criteria that may reflect safety-related management attitudes. Once suitable behavioral indices of safety-related attitudes have been agreed upon, research should be conducted to identfy the extent to which plant management practices differ on these indices and to determine methods for generating desirable changes. This research is considered to be of medium importance and should be initiated within three to five years. We recommend a duration of one year with two person-years of service from either a career human factors professional or an industrial/organizational psychologist or both.

4.5.4 Shift Duration and Rotation

We recommend that research be conducted to determine whether and under what conditions operator performance in the control room measurably deteriorates. Particular attention should be devoted to identifying performance measures and physiological indices that are likely to be sensitive to loss of alertness and cumulative fatigue. Assuming that performance deterioration is documented, research should be conducted to identify variables that influence its severity. Variables to be investigated should include, at least, shift duration, shift rotation schemes, and procedures for eliminating boredom. Work should also be performed on the redesign of the LER methods so that an appropriate and useable data bank of events can be related to independent variables logically associated with shift length, work/rest cycles, and shift duration.

The recommended actions are judged to be of high importance. They should be started within one to two years and require three years to complete. Necessary resources are a total of 10 person-years professional services and access to control room and control room personnel. Personnel requirements include a career human factors professional or experimental psychologist and a work physiologist. The implementation of this research is dependent upon (1) development of unobtrusive, sensitive measures of performance deterioration or long-term alertness, and (2) cooperation of management, union, and plant personnel.

4.4.5 Factors Affecting Job Satisfaction

If industry does not take the lead in research leading to the minimization of turnover and maximization of job satisfaction among ROs and SROs, we recommend that research be conducted to establish recent turnover rates and rates that are predictable for the next two to three years in the nuclear power industry. (Attention should be directed to the distinction between personnel who leave the industry and those who move to a new position within the industry.) If turnover rates are judged to be excessive in relation to safety considerations, research should be performed to identify causes and changes in industry or NRC practices that would be necessary to reduce them significantly. Identification should be made of the reward/feedback/professional growth structure necessary to minimize job dissatisfaction and to maximize stability.

These high importance actions should be initiated immediately and should continue as long as periodic assessment of trends is necessary. The work should require two person-years per year of services by career human factors professionals or industrial/organizational psychologists or both.

A recommended schedule and estimates of staffing for the technical requirements in the area of personnel and staffing are summarized in Figure 5.

4.6 Problem Areas in Training

Our recommendations in the area of training are directed at instructional development, licensed and non-licensed personnel training, and training equipment.

4.6.1 Instructional System Development

In much the same way that the physical man-machine interface should be developed using systematic analysis, so should the training components of the nuclear power system be developed. We recommend that a point of contact be established within the NRC to coordinate the training-related research and development among the NRC groups with those of INPO and EPRI. This activity will also include ensuring the dissemination of training-related plant operating experience data from LERs and SALP (or 766 File), and from other observations of training-related deficiencies in plant personnel performance that should be elicited routinely from IE resident inspectors. This program should also monitor the adequacy of training programs used for NRC personnel. This requirement is highly important and should be initiated immediately. Its implementation requires an NRC staff educational technologist.

The NRC should publish a Regulatory Guide for Instructional System Development procedures suitable for use by the nuclear power industry for the development of training for all plant personnel. For each plant personnel training program, the NRC should use the regulatory guide to evaluate the adequacy of the behavioral objectives and antecedent data. The NRC should monitor the procedures used by industry for the development of training to ensure that they are suitable for the development of comprehensive training programs and quality control. The importance of this requirement is high. The recommendations should be implemented within one to two years. Development of the regulatory guide should require one year. This should be followed by continuous monitoring and evaluation. The development of the regulatory guide should require one person-year of services from an educational technologist with support from subject matter experts. Evaluation and monitoring will require 0.1 to 0.5 person-year per plant position.

PROBLEM AREA AND TECHNICAL REQUIREMENT	START TIME, DURATION, AND PERSONNEL REQUIREMENT										
	1	2	3	4	5	6	7	8	9	10	
4.5.1 PERSONNEL SELECTION – PRACTICES & STANDARDS											
● RESEARCH ON VALIDATION OF SELECTION PROCEDURES	1	1	1	1	1	1	1	1	1	1	H
● RESEARCH ON EFFECTS OF ACCIDENT–GENERATED STRESS ON PERSONNEL		4	4	RE-EVALUATE							H
● MONITOR & EVALUATE INDUSTRY BEHAVIORAL RELIABILITY PROGRAMS			0.5	0.5	0.5	INDEFINITE					M
● RESEARCH ON NEW TECHNOLOGY TESTING PROCEDURES						2	2	2	2	2	L
4.5.2 OPERATOR CERTIFICATION & LICENSING											
● RESEARCH TO DEVELOP OBJECTIVE PERFORMANCE STANDARDS FOR RO, SRO, & SS		3	3	3							H
● RESEARCH TO DEVELOP QUALIFICATIONS FOR NON-LICENSED PERSONNEL		5	5								H
● RESEARCH TO ASSESS PROGRESS THROUGH TRAINING PROGRAMS						1					L
● RESEARCH ON TRADEOFF OF FORMAL EDUCATION VERSUS EXPERIENCE		2.5	2.5								M
4.5.3 STAFFING & ORGANIZATIONAL CHARACTERISTICS											
● RESEARCH TO DEVELOP CRITERIA FOR ASSESSING ORGANIZATIONAL VARIABLES			2								M
4.5.4 SHIFT DURATION AND ROTATION											
● MODIFY LER SYSTEM: DATA FOR SHIFT LENGTH, ROTATION, ETC.		STAFF									H
● RESEARCH ON OPERATOR PERFORMANCE DETERIORATION		3	3	3							H
● RESEARCH ON VARIABLES INFLUENCING OPERATOR PERFORMANCE DETERIORATION					3	3	3				H
4.5.5 FACTORS AFFECTING JOB SATISFACTION											
● RESEARCH ON JOB TURNOVER RATES	2	2	2	2	2	2					H

FIGURE 5. SCHEDULE FOR MEETING TECHNICAL REQUIREMENTS IN PERSONNEL & STAFFING

Research should be performed on retention of critical skills and knowledges for each plant job category. The results of the research should be used to develop a guide for determining refresher training requirements which will be implemented in the ISD regulatory guide. This high importance research should be started within three to five years and should require a duration of three years. Resources required are four person-years per year of services from career human factors professionals plus support from training equipment programmers and an educational technologist for the regulatory guide update.

4.6.2 Licensed Personnel Training

In addition to the recommendations pertaining to Instructional Systems Development, the NRC should adopt the recommendations of NUREG/CR-1750, Section 2.10, License Training Instructors, which are summarized as:

1. Before receiving any instructional assignments, all training personnel (including Training Managers) should attend a certified course or program specifically aimed at familiarization with an application of instructional methods and techniques.

2. During periodic audits, ensure that instructional staffs have received training or possess the equivalent education necessary to demonstrate effective training practices.

3. Utilities should implement periodic workshops or retraining programs for assessing and improving instructional skills.

4. In evaluating instructors, utilities should consider several measures, including (a) meeting of well-stated, valid objectives, (b) periodic observation by an instructional specialist, (c) trainee feedback, (d) trainee performance on the job (supervisor feedback), and (e) training coordinator or senior instructor observation using a detailed structural observation list.

The importance of these recommendations is high. They should be implemented immediately by NRC staff.

4.6.3 Non-Licensed Personnel Training

The NRC should adopt the recommendations of NUREG/CR-1750, Section 2.10, as summarized in the preceding paragraphs, for specified non-licensed personnel training, as well as for licensed personnel. This action should be taken immediately.

4.6.4 Training Equipment

The design and incorporation of training equipment into training programs for nuclear power plant personnel has made little use of modern technology except in the simulators designed for control room operators. There is no program for the validation of training (or testing) carried out on training equipment, i.e., SIMCERT or TEA studies. The NRC should publish a regulatory guide for the certification of the training effectiveness of training simulators and other devices upon which terminal training objectives will be met. This recommendation is rated high in importance. It should be implemented within one to two years and should require a year to accomplish. Estimated resources required are two person-years, including a career human factors professional and subject matter experts.

The recommended schedule and staffing estimates for the technical requirements in the area of training and training equipment are summarized in Figure 6.

4.7 Incident Response Plan and NRC Facilities

Human factors issues within the broad area of emergency preparedness are beyond the scope of the present contract and report. However, we were requested to consider specific aspects of the incident response plan and related NRC facilities. Our review was concerned with (1) the incident response plan, (2) the NRC operations center, (3) utility emergency response facilities, and (4) the safety parameter display system (SPDS).

4.7.1 Incident Response Plan

A systems analysis should be done to identify more precisely the behavioral and human factors issues related to planning for response to emergencies. Many people will be involved if an emergency response plan is implemented, and the preparedness of these people is a significant human factors concern. We consider that this analysis is of relatively medium importance and should be started within the next year or two. It should be completed within three years after starting and require three person-years of technical resources. Personnel should include a career human factors professional and a social scientist experienced in emergency planning and behavior.

4.7.2 NRC Headquarters Operations Center and Regional Facilities

A complete systems analysis of the NRC incident response need and the facilities to meet that need should be done to

PROBLEM AREA AND TECHNICAL REQUIREMENT	START TIME, DURATION, AND PERSONNEL REQUIREMENT										
	1	2	3	4	5	6	7	8	9	10	
4.6.1 INSTRUCTIONAL SYSTEM DEVELOPMENT											
• ESTABLISH NRC COORDINATOR OF TRAINING ACTIVITIES	IMMEDIATE & CONTINUING – staff career prof. and educational technologist										H
• DEVELOP AND PUBLISH REG GUIDE FOR ISD; MONITOR TRAINING PROGRAMS		STAFF	15	12	12	10	10	10	10	10	H H
• RESEARCH ON RETENTION OF SKILLS & KNOWLEDGES				4	4	4					H
4.6.2 LICENSED PERSONNEL TRAINING											
• ADOPT RECOMMENDATIONS OF SECTION 2.10, NUREG/CR-1750	IMMEDIATELY										H
4.6.3 NON-LICENSED PERSONNEL TRAINING											
• ADOPT SECTION 2.10, NUREG/CR-1750 FOR SPECIFIED NON-LICENSED PERSONNEL	IMMEDIATELY										H
4.6.4 TRAINING EQUIPMENT											
• ISSUE REG GUIDE FOR CERTIFICATION OF TRAINING SIMULATORS		2									H

FIGURE 6. SCHEDULE FOR MEETING TECHNICAL REQUIREMENTS IN TRAINING

derive human performance requirements. These requirements, which relate primarily to decision making tasks, can then be further task analyzed to determine specific information and communication requirements, job designs, and the necessary staffing and organization. The proper human factors evaluation of the NRC Operations Center can then be performed and design specifications can be prepared based on these analyses. This highly important recommendation should be implemented within one to two years. We recommend a one-year program with personnel resources of three person-years. Personnel required are career human factors professionals and the NRC Operations Center staff.

4.7.3 Utility Emergency Response Facilities

The utility emergency response facilities considered by us were the Technical Support Center, onsite Operational Support Center, nearsite Emergency Operations Facility, and the Nuclear Data Link. A system analysis should be conducted to determine the human factors requirements for the emergency response facilities. This should be a straightforward analysis starting with the identification of major functions of each of the facilities and then some suitable form of job or task analysis to identfy actions and responsibilities of the user personnel. Design of specific displays, procedures, and facility arrangement would evolve from the analysis. The NRC should provide guidance on the conduct of this system analysis and should further provide evaluation criteria for the review of designs submitted in accordance with that guidance. These high importance actions should be initiated within one to two years. The program is estimated to require two years and require technical personnel resources of eight person-hours. The personnel should include career human factors professionals, a nuclear engineer, and an instrumentation and controls engineer.

4.7.4 Safety Parameter Display System

The safety parameter display system (SPDS) is a part of the emergency response facilities but is being treated separately because of its significance in terms of human factors. Technical feasibility does not represent a problem for SPDS. Rather, the reverse might be true in that the state of the art in displays and computer systems may very well be driving the design of many SPDS alternatives, rather than the functional and user requirements. The need for SPDS has not been established from any system or task analysis effort. A well-designed control room may be satisfactory without an SPDS. There is some danger that undue reliance upon an SPDS may result in failure to make more basic human engineering design improvements in the control room. Therefore, a thorough systems analysis should be done before SPDS is implemented. The job/task analysis being done by INPO and the RO task analysis being done by NRC must be coordinated with any similar analysis for SPDS. If any SPDS is to be developed, the following must be an integral part of the human factors considerations:

(a) evaluate the need for a backup SPDS as specified in NUREG-0696 (80),

(b) if a backup SPDS is required, evaluate the need to install separate seismic instrumentation in a concentrated area,

(c) review the potential conflict with Regulatory Guide 1.97 (144), and

(d) develop evaluation criteria for user acceptance.

This recommended action is of the highest importance. It should be initiated immediately. (The reader is also encouraged to note the discussion in Section 3.1.1 of Volume 2 of this report.) We estimate that the work will require from one to two years to complete. Resources required are NRC staff members, including career human factors professionals, computer systems experts, and reactor safety parameter matter experts.

The recommended schedule and staffing estimates for the technical requirements in the area of the incident response plan and NRC facilities are summarized in Figure 7.

PROBLEM AREA AND TECHNICAL REQUIREMENT	START TIME, DURATION, AND PERSONNEL REQUIREMENT										
	1	2	3	4	5	6	7	8	9	10	
4.7.1 INCIDENT RESPONSE PLAN											
● PERFORM SYSTEMS ANALYSIS TO IDENTIFY HUMAN FACTORS ISSUES		1	1	1							M
4.7.2 NRC HEADQUARTERS OPS CENTER AND REGIONAL FACILITIES											
● PERFORM HUMAN FACTORS EVALUATION OF NRC OPERATIONS CENTER		3									H
4.7.3 UTILITY EMERGENCY RESPONSE FACILITIES (ERF)											
● PROVIDE GUIDANCE AND REVIEW FOR HF ANALYSIS OF ERF		4	4								H
4.7.4 SAFETY PARAMETER DISPLAY SYSTEM											
● EVALUATE NEED, EFFECTS, AND POSSIBLE INTEGRATION OF SPDS	IMMED.– STAFF										H

FIGURE 7. SCHEDULE FOR MEETING TECHNICAL REQUIREMENTS FOR INCIDENT RESPONSE PLAN AND NRC FACILITIES

5.0 SUMMARY OF RECOMMENDED PLANS AND REQUIREMENTS

Section 4.0 of this volume described the recommended elements of the long-range plan for human factors in nuclear reactor regulation. Volume 2, Section 4.0 discusses each item in more detail, while Volume 3 offers rationale, documentation, and background discussion for each of the recommended elements and actions.

For each recommended element in the plan we have given estimated person-years of professional activity needed to meet the requirement. In addition, we have indicated particular unique facilities (e.g., simulators) necessary to perform some of the work. It is beyond our ability and responsibility to translate these estimates into monetary costs. However, at the request of the NRC, we have summarized the manpower costs in this plan, by general category of activity. It is hoped that this summary, provided in Table 1, will permit NRC management to budget appropriately and to compare this plan with other projections of related expenditures.

TABLE 1. SUMMARY OF MANPOWER ESTIMATES IN PERSON-YEARS, EXCLUSIVE OF ROUTINE NRC STAFF ACTIVITIES.

Technical Requirement Area	Year 1	2	3	4	5	6	7	8	9	10
1. General Areas	6	7	5	5	5	5				
2. Human Engineering	2	7	9	5	5	10	10	10	10	
3. Procedures and Operator Aids		5	4	5	2	7	5	3	2	1
4. Personnel & Staffing	3	21	23	10	7	8	6	4	3	3
5. Training		2	15	16	16	14	10	10	10	10
6. Incident Response Plan & NRC Facilities		8	5	1						
TOTALS	11	50	61	42	35	44	31	27	25	14

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LIST OF ACRONYMS AND INITIALISMS

The following acronyms and initialisms have been used in this report. They are listed in alphabetical order for the convenience of the reader.

ACRS	Advisory Committee for Reactor Safeguards
AE or A/E	Architect-Engineer
AEC	Atomic Energy Commission
AEOD	(Office of) Analysis and Evaluation of Operational Data
AFSCDH	Air Force Systems Command Design Handbook
AFSCR	Air Force Systems Command Regulations
AIF	Atomic Industrial Forum
ANS	American Nuclear Society
ANSI	American National Standards Institute
BNL	Brookhaven National Laboratory
BOP	Balance of Plant
BPNL	Battelle Pacific Northwest Laboratory
BTP	Branch Technical Position
BWR	Boiling Water Reactor
CAI	Computer-Aided Instruction
CEMS	Critical Equipment Monitoring System
CFMS	Critical Function Monitoring System
CODAP	Comprehensive Occupational Data Analysis Program
CP	Construction Permit
CR	Control Room
CRDR	Control Room Design Review
CRGR	Committee to Review Generic Requirements

CRT	Cathode-ray Tube
DASS	Disturbance Analysis and Surveillance System
DCRDR	Detailed Control Room Design Review
DEDROGR	Deputy Executive Director for Regional Operations and Generic Requirements
DHFS	Division of Human Factors Safety
DOD	Department of Defense
DOE	Department of Energy
EDO	Executive Director for Operations
EEI	Edison Electric Institute
EOF	Emergency Operations Facility
EPRI	Electric Power Research Institute
ERF	Emergency Response Facilities
ESF	Engineered Safety Feature
FAA	Federal Aviation Administration
FSAR	Final Safety Analysis Report
HE	Human Engineering
HEP	Human Error Probability
HER	Human Error Rate
HFEB	Human Factors Engineering Branch
HF	Human Factors
HFE	Human Factors Engineering
HFS	Human Factors Society, Inc.
HIAPSD	Handbook of Instructions for Aerospace Personnel Subsystem Designers
HTGR	High-Temperature Gas-Cooled Reactor
IE	(Office of) Inspection and Enforcement
IEEE	Institute for Electrical and Electronics Engineers

IEORS	Integrated Operational Experience Reporting System
INEL	Idaho National Engineering Laboratory
INPO	Institute of Nuclear Power Operations
IREP	Interim Reliability Evaluation Program
ISD	Instructional System Design
ISEG	Independent Safety Engineering Group
ISFSI	Independent Spent Fuel Storage Installation
JPA	Job Performance Aid
LER	Licensee Event Report
LLNL	Lawrence Livermore National Laboratory
LLTF	Lessons Learned Task Force
LMFBR	Liquid Metal Fast Breeder Reactor
LOCA	Loss-of-Coolant Accident
LOFT	Loss-of-Fluid Test
LQB	Licensee Qualifications Branch
M-M	Man-Machine ("Man" is used in the generic sense.)
NDL	Nuclear Data Link
NPP	Nuclear Power Plant
NPRDS	Nuclear Plant Reliability Data System
NRC	U. S. Nuclear Regulatory Commission
NREP	National Reliability Evaluation Program
NRR	(Office of) Nuclear Reactor Regulation
NSAC	Nuclear Safety Analysis Center
NSSS	Nuclear Steam Supply System
NTOL	Near-Term Operating License
ODPS	Operator Diagnostic and Display System
OJT	On-the-job Training

OL	Operating License
ORAU	Oak Ridge Associated Universities
ORNL	Oak Ridge National Laboratory
OSC	Operational Support Center
PDRI	Personnel Decisions Research Institute
PMS	Performance Measurement System
PORC	Plant Operations Review Committee
PRA	Probabilistic Risk Analysis
PSF	Performance Shaping Factor
PTRB	Procedures and Test Review Branch
PWR	Pressurized Water Reactor
RES	(Office of) Nuclear Regulatory Research
RO	Reactor Operator
SAT	Systems Approach to Training
SER	Safety Evaluation Report
SIG	Special Inquiry Group
SIMCERT	Simulator Certification
SME	Subject Matter Expert
SNL	Sandia National Laboratory
SPAR	Standards Project Authorization Request
SPDS	Safety Parameter Display System
SRG	Special Review Group (of the Office of Inspection and Enforcement)
SRP	Standard Review Plan
SRO	Senior Reactor Operator
SS	Shift Supervisor
STA	Shift Technical Advisor
TAG	Technical Advisory Group

TEA	Training Effectiveness Analysis
TIM	Task Identification Matrix
TSC	Technical Support Center
TMI-2	Three Mile Island, Unit Two
TVA	Tennessee Valley Authority
USAF	United States Air Force

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This comprehensive long range human factors plan for nuclear reactor regulation was developed by a Study Group of the Human Factors Society, Inc. This Study Group was selected by the Society to provide a balanced, experienced human factors perspective to the application of human factors scientific and engineering knowledge to nuclear power generation.

The report is present in three volumes. Volume 1 contains an Executive Summary of the 18-month effort and its conclusions. Volume 2 summarizes all known nuclear human factors activity, evaluating this activity, wherever adequate information is available, and describes the recommended long-range (10-year) plan for human factors in regulation. Volume 3 elaborates upon each of the human factors issues and areas of concern that have led to recommendations in the long range plan.

17. KEY WORDS AND DOCUMENT ANALYSIS — 17a. DESCRIPTORS

Human factors engineering	Training devices
Human engineering	Human feasibility
Procedures	System integration
Job performance aids	System engineering
Personnel selection	Annunciators/alarms
Staffing	Maintainability
Training	Operator licensing

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