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HUMAN FACTORS PROGRAMS FOR HIGH-LEVEL RADIOACTIVE WASTE HANDLING SYSTEMS

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ABSTRACT

Human Factors is the discipline concerned with the acquisition of knowledge about human capabilities and limitations, and the application of such knowledge to the design of systems. This paper discusses the range of human factors issues relevant to high-level radioactive waste (HLRW) management systems and, based on examples from other organizations, presents mechanisms through which to assure application of such expertise in the safe, efficient, and effective management and disposal of high-level waste. Additionally, specific attention is directed toward consideration of who might be classified as a human factors specialist, why human factors expertise is critical to the success of the HLRW management system, and determining when human factors specialists should become involved in the design and development process.

INTRODUCTION

For many in the nuclear power industry, the first awareness of *human factors* issues came as a result of the analysis of events which led to the incident at Three Mile Island (TMI). As a consequence, many in this industry came to view *human factors specialists* as those having concern for such issues as control characteristics and operating procedures. In the computer industry or among software system developers, on the other hand, development of display screen layouts and menu hierarchies are typical human factors activities which define the domain of the human factors specialist. In still other venues, the focus of human factors application--which, as we have seen, may define the human factors specialist for a particular venue--may be on such issues as physical size (i.e, anthropometrics), strength (biomechanics), memory (information processing), visual acuity (perceptual abilities), and operating (e.g., thermal stress) or organizational (job design) environments.

Each of these is, indeed, an application of human factors expertise and, assuming proper credentials, the diverse collection of associated practitioners could each appropriately be considered a human factors specialist. Speaking collectively, human factors specialists have expertise in all these areas--although, of course, few if any claim expertise in all--and today's complex systems present many opportunities for application of human factors expertise across a wide array of human-system interfaces. This paper/presentation will provide an understanding of the range of human factors issues relevant to high-level nuclear waste management systems and, based on examples from other organizations, will discuss mechanisms through which to assure application of such expertise in the safe, efficient, and effective management and disposal of high-level waste.

HUMAN FACTORS: "WHAT"

The field of human factors began to take shape during World War II in response to myriad problems associated with military systems which were not engineered for ease of installation, operation, maintenance, support and/or disposal. What were then called *engineering psychologists* in the United States and *ergonomists* in Great Britain began studying human characteristics and applying this information to the design of the systems of war (see Christensen[1] for an extended discussion). From that time on, the defense arena has provided the greatest support for human factors involvement in systems design, perhaps due to the complexity of the systems as well as to the criticality of proper system functioning.

Unfortunately, despite its fifty year history, the field has not yet coalesced sufficiently to enable selection of a single name, and the discipline is known in various quarters as human factors, human engineering, human factors engineering, engineering psychology, and ergonomics among others. Indeed, the extent, if any, to which each of these terms represents a distinct focus within the field is still subject to debate (see e.g., Chapanis[2] and Sheridan[3]). For present purposes, *human factors* will be used to designate the field encompassed by all these terms, and *human factors specialists* will be used to refer to those professionals who conduct research in, or apply knowledge of, human factors.

Human Factors may be viewed as the discipline concerned with the acquisition of knowledge about human capabilities and limitations, and the application of such knowledge to the design of systems. The attempt is, of course, to take maximum advantage of our capabilities while minimizing the impact our limitations have on system performance. The approach is to maximize system effectiveness and efficiency while minimizing any adverse impact on workers. In high-level nuclear waste handling, then, human factors expertise might beneficially be brought to bear on such diverse issues as design of displays and controls for the remote handling of waste canisters; impact of thermal stress associated with use of personal protective equipment; effective presentation of information required to verify and monitor waste status; and analysis of worker roles and staffing requirements associated with manual versus partially- or fully-automated operations.

Figure 1 depicts the basic functions typically performed by human-machine systems. One important task--called function allocation--typically performed by human factors specialists in conjunction with engineering designers, is determination of the extent to which each of these functions (or subfunctions) should be performed by human, hardware, and/or software elements in order to best achieve the goals of the system.

A detailed discussion of the variables which impact human effectiveness in performance of each of these functions is beyond the scope of this paper. Nevertheless, a listing of a few such variables associated with one function may prove instructive with respect to the kinds of issues focused upon by human factors specialists. We receive information, especially work-related information, primarily through our vision and hearing senses. Our ability to do this *sensing/information receiving* effectively depends on such variables as:

-presentation characteristics such as size, color, and font of letters and numbers, and organization of document (in both hard- and soft-copy formats);

-individual characteristics such as visual acuity, level of alertness, amount of experience, and personality;

-task characteristics such as pace of work, physical and mental workload, and incentives; and

-environmental characteristics such as ambient illumination, time of day, effects of personal protection equipment, and "stress" from a variety of work related and non-work related sources.

Each of these variables, and others, has the potential to affect a worker's ability to "receive" the information correctly. Errors in performing this function may affect performance of other functions. For example, in verifying the classification of a particular shipment of waste, a sensing/information receiving error could result in mis-classifying the waste and, then, to an incorrect *decision* regarding proper handling of the shipment. Similarly,

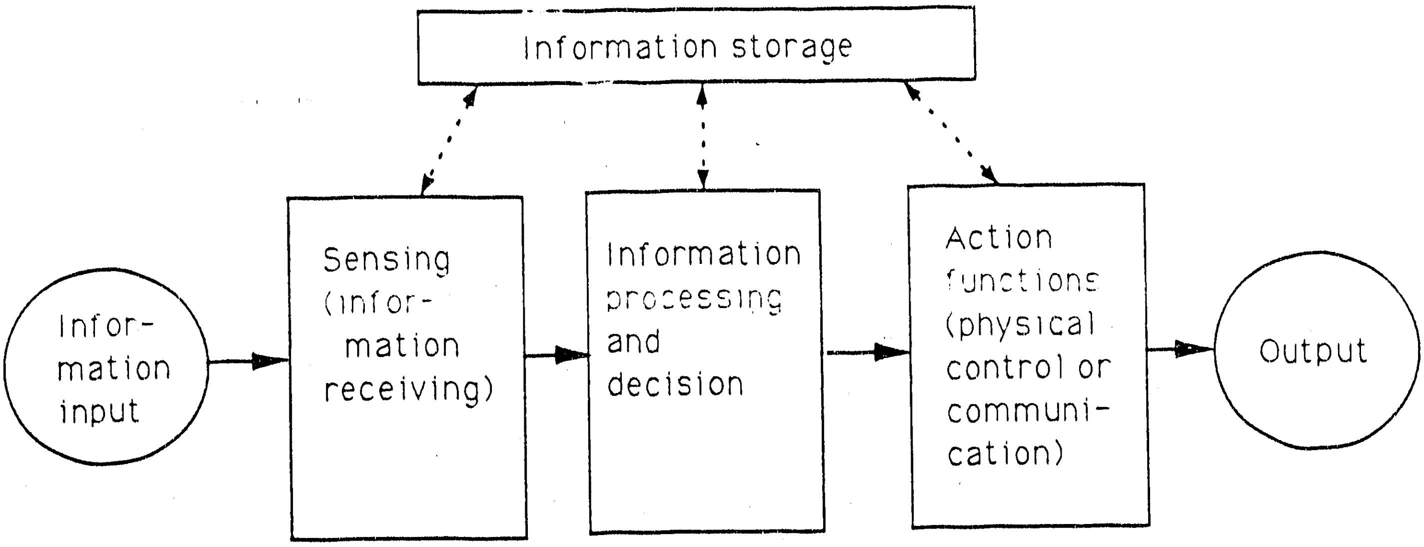

Figure 1. Types of basic functions performed by human or machine components of human-machine systems (from Sanders and McCormick, ref. 4).

while aligning fuel assemblies for insertion into canisters, a misperception could impair the accuracy and effectiveness of the *physical control* required to perform the task, thereby resulting in delays and/or damage to the shipment or handling equipment.

A similar set of variables which might impair the ability of a human to accomplish each of the other system functions could easily be compiled. It may be more useful or present purposes, however, to define or describe a human factors specialist, to detail the benefits which accrue through application of human factors expertise, and to specify a mechanism through which such expertise can be incorporated into the design and development of an effective HLRW management system.

HUMAN FACTORS: "WHO"

Although individuals from many academic backgrounds are represented in the *Human Factors Society*, the two most frequently seen are psychology and engineering (see, for example, Sanders and McCormick[4]). It was once the case that human factors specialists typically earned their graduate degrees in such fields as experimental psychology or industrial engineering before acquiring their human factors "training" on-the-job. Increasingly, however, those entering the profession have received specialized training in human factors graduate degree programs (a directory of which is published by the *Human Factors Society*),[5] and this may serve as one indicator of a qualified human factors professional, especially for those without lengthy work histories.

Professionals from related disciplines such as computer science, industrial engineering, cognitive psychology, or exercise physiology frequently perform work in the area of overlap between human factors and their own discipline. Such areas of overlap, and the resulting interdisciplinary collaborations which result, do not mean that a human factors specialist is also qualified as a computer scientist/cognitive psychologist/etc., or vice versa.

The absence of a human factors professional certification or licensing mechanism has contributed to problems in this latter regard. For example, many organizations rushed to secure human factors expertise following such supposed "human error"-caused disasters as TMI and the mistaken, yet intentional, destruction of Iranian and Korean commercial airliners in flight by the U.S. and Soviet military, respectively. Since the field is relatively small--about 4,000 members of the *Human Factors Society* world wide--the resulting shift in the human factors supply-demand equation is likely to have created a number of opportunities for those with little more than a knowledge of human factors jargon (see Jahns[6] for a discussion of issues in professional certification).

HUMAN FACTORS: "WHY"

In a series of reports to the U.S. Congress and the U.S. Secretary of Energy, the U.S. Nuclear Waste Technical Review Board has affirmed the value of incorporating human factors expertise into the spent nuclear fuel and high-level waste disposal program. The Board has repeatedly recommended establishment of a human factors program because:

-these programs are *acknowledged to contribute substantially to the reliability and safety of complex systems*;[7]

-*systems acquisition programs in other governmental agencies routinely provide policy statements, guidelines, and criteria documents in human factors...*;[8]

-*the DOE itself is adding specific people with human factors training to technical review groups and has directed that human factors considerations be incorporated in operational planning* ;[9] and

-*a human factors program has been recognized as a needed discipline for nuclear safety in general.*[7]

Although the focus of the Board's recommendations is specifically on waste transportation, the potential benefit of such programs is applicable to most or all aspects of HLRW management systems. These systems are no less complex than many military or nuclear power systems, and they require numerous human interfaces to enable, for example, analysis, manipulation, and monitoring of the waste in addition to those interfaces associated with transportation. In the management of HLRW, as will be more thoroughly discussed in other papers presented at this session, human factors issues are evident in primary operations (i.e., waste processing, transport, storage, and disposal) as well as in such elements as waste certification program procedures and laboratory analysis protocols which are developed in support of these operations.

In part because of the complexity of HLRW management systems, the U.S. Department of Energy (DOE) Office of Civilian Radioactive Waste Management (OCRWM) has recently noted that *systems engineering is essential for the success of the* [waste management] *program because it provides the means for identifying and controlling the many interfaces among the elements of the system, coordinating the multiple scientific and engineering disciplines involved in the program, and optimizing the design and operation of the system.*[10] As a consequence, use of state-of-the-art systems engineering techniques has been designated as one of the *technical principles* on which the OCRWM's program is founded. Fortunately, OCRWM's reliance on a system engineering approach provides the ideal platform on which to base a human factors program because of the inherent compatibility between these two. Citing U.S. Air Force Regulations, Woodson, Tillman, & Tillman describe human factors as *that component of systems engineering which seeks to optimize the system by integrating the human performance necessary to operate, maintain, support, and control the system in its intended operational environment.*[11]

From the above, it seems reasonable to conclude that:

-application of human factors expertise is a critical, if not essential, element to the successful deployment of large-scale and/or complex systems such as those associated with HLRW management; and that

-the incorporation of such expertise has already been greatly facilitated by the decision to utilize a systems engineering approach in conceptualizing, developing, and designing waste management facilities and operations.

As a "bonus", the Department of Defense (DoD) has noted that *the investment in human engineering is relatively small compared to other areas. The return on the investment can be relatively high.*[12]

HUMAN FACTORS: "HOW"

Having addressed the issues of what human factors is, who might be considered a human factors specialist, and why human factors expertise is critical to the success of the HLRW management system, we turn now to the question of how human factors expertise can most effectively be brought to bear on the challenges in HLRW management. The answer is "through development and implementation of a *human factors program.*"

As previously indicated, the DoD has historically been the strongest supporter of human factors involvement in systems design. Current DoD policy is that *human factors engineering shall be an integral part of planning and conceptual efforts, development projects, and acquisition programs to include modifications*, and the procedure specified to accomplish this is that *a human factors engineering program will be established for each systems acquisition...*[13]

The elements of a DoD human factors program are detailed in the Military Specification MIL-H-46855.[14] Among the stated purposes of this document (and, of course, of the specified human factors activities) is to provide assurance that:

-system operational requirements are achieved through appropriate utilization of the human "component";

-potential error inducing equipment designs are eliminated or controlled;

-design features are not hazardous; and that

-operating and maintenance procedures are efficient, reliable, and safe.

These objectives are attained by incorporation of human factors expertise in each of the three major areas of systems development: analysis, design and development, and test and evaluation. During the analysis phase, the human factors specialist leads or participates in analysis of such aspects as operator physical and mental workload demands, critical tasks, and information flow requirements in addition to the previously discussed allocation of functions.

In the design and development stages, human factors professionals may build mockups and models as well as computer simulations of system elements in order to assess the suitability of specific design features in meeting system goals. They also develop and review detail design drawings to evaluate system conformance to applicable human factors specifications such as the DoD's human factors design criteria document, MIL-STD-1472.[15] Finally, during system test and evaluation, human factors staff plan and conduct appropriate tests to verify that the system can be installed, operated, maintained, and supported by the intended personnel under the conditions forecasted.

Provision is made, and guidance provided, within the specifications of MIL-H-46855 to tailor the human factors program requirements to accommodate, for example, cost limited acquisitions and systems having a different nature/extent of anticipated human interfaces. Given the size, complexity and criticality of the HLRW management system, it is likely that greater rather than lesser emphasis should be placed on development and implementation of a human factors program.

Within the DoD, each of the services has implemented programs which include or focus primarily on human factors. Perhaps the most successful of these is the Army's *Manpower, and Personnel Integration Program*, commonly known as MANPRINT.[16] It has been reported that a major impetus for instituting this program was that *after a number of experiences with technically elegant systems that failed in the field because they could not be operated or maintained effectively, the concept of design excellence began to broaden to include the human operator.*[17] This program is a comprehensive management and technical effort developed to assure consideration of information related to human factors, manpower, personnel, training, system safety, and health hazards throughout all development and acquisition activities.

The success of MANPRINT in improving system quality and in yielding cost savings for a number of major programs has been noted by the Federal Aviation Administration (FAA) which recently put forth *The National Plan For Aviation Human Factors*.[17] In this plan, the FAA attributes a large part of MANPRINT's success to, among other things, the "institutionalization" of human factors principles within the Army's procurement process--that is, that a system's human performance characteristics are a heavily-weighted element of each procurement decision. Finally, as a central aspect in their plan, the FAA will seek to assure the "organizational commitment" to formally consider the human factors of every facet of the aviation system.

Based on these examples, the message is clear:

-thorough consideration of the human "component" throughout the development of complex systems is essential to the success of the fielded system;

-the cost of these efforts compares favorably with the savings realized; and

-development and incorporation of a human factors program into new venues such as that represented by the HLRW management system may be facilitated by the suitable adaptation of any of a number of well-established, successful programs.

The question which remains is...

HUMAN FACTORS: "WHEN"

Although many human factors approaches and methods have been found to adapt reasonably well to the "retro-fit" of existing systems (see e.g., NUREG/CR-2833),[18] it is unquestionably more effective for human factors professionals to be involved throughout the systems design process: from concept development through deployment and, as appropriate, disposal. The earlier a human factors specialist is brought into this process, the fewer design features will have been "frozen"; the more pervasive his/her influence can be; the greater positive impact he/she can have on the design; and the more likely the human factors expert will be a "value added" contributor rather than an after-the-fact critical evaluator.

In short, when should a human factors specialist be brought on board? The answer, of course, is "Now"!

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