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TRAINING RELATED RESEARCH AND DEVELOPMENT CONDUCTED AT OAK RIDGE NATIONAL LABORATORY FOR THE U.S. NUCLEAR REGULATORY COMMISSION*

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Abstract

For a number of years Oak Ridge National Laboratory (ORNL) has conducted a sizeable program of human factors research and development in support of the Office of Nuclear Regulatory Research of the U.S. Nuclear Regulatory Commission (NRC). The history of this effort has in many ways paralleled the growth of human factors R&D throughout the nuclear industry and the program has contributed to advances in the industry as well as to NRC regulatory and research programs. This paper reviews the major projects and products of the program relevant to training and concludes with an identification of future R&D needs.

Introduction

Since 1978, ORNL has conducted a number of research and development programs for the NRC's Office of Nuclear Regulatory Research related to human performance, personnel qualifications, personnel training and licensing, nuclear power plant (NPP) simulators, human reliability and other human factors issues. The results have contributed to the technical basis for research and regulatory action by NRC and therefore to the industry as a whole. This paper highlights those projects and products related to NPP personnel training. The R&D was performed under two major programs: "Safety-Related Operator Actions" (FIN No. B0421) and "NPP Personnel Qualifications and Training" (FIN No. B0466), and the summary review that follows is structured according to those two programs. Conclusions are then provided as to future R&D needs relevant to NPP personnel training.

Safety-Related Operator Actions Program

The Safety-Related Operator Actions Program, perhaps better recognized for its early contributions in the area of operator performance data collected from NPP simulator experiments and plant records, [1-6] also included several studies directly applicable to personnel training. The earliest of these was an assessment of the capabilities and usage of simulators in the nuclear power industry, immediately following the Three-Mile Island-2 (TMI-2) event. [7] That study provided a base of information for future NRC and industry action, identified some areas of weakness (in particular in the usage of simulators in training programs rather than in design), and made a series of recommendations regarding simulators, their use in operator training programs, NRC regulatory action and research needs. A fundamental recommendation, underlying most of the others, was that the NRC and the industry should move to adapt and adopt a systems approach to training development, one which is performance-based and which recognizes simulators as a integral part of training system development.

A more in-depth analysis of simulator characteristics and approaches to assessing and evaluating simulator requirements was subsequently carried out. [8-9] It further emphasized the need for a systems approach to training and made detailed recommendations in four areas:

1) Adaptation and implementation of Systems Approach to Training/Instructional Systems Development (SAT/ISD) Methods.
2) Simulator fidelity assessment.
3) The role of NRC in simulator (training system) development and evaluation.
4) Improvements to ANSI/ANS 3.5 (the industry standard for training simulator design and usage).

The results of that study contributed significantly to NRC and industry action regarding training simulators.

A third R&D effort within the Safety-Related Operator Actions Program which contributed indirectly to training and a number of other human factors areas was the development and demonstration of a methodology for control-room-crew task analysis using simulators and related performance measurement tools that were being employed in simulator experiments. Two pilot studies were completed; one for pressurized water reactor [10] and one for boiling water reactor [11] control rooms. These pilot studies formed the basis for the methodology employed in the subsequent development of the NRC "Task Analysis of Nuclear Power Plant Control Room Crews." [12]

NPP Personnel Qualifications and Training Program

Five significant products applicable to training research and/or training program development and evaluation were produced under this program which was initiated in 1982 and will be completed this fiscal year. Four of these are described below. These four programs were all directed toward providing NRC with the technical basis for and some specific tools/ methods for adapting and implementing the Systems Approach to Training. The fifth product, a methodology and handbook [13-14] for evaluation of simulation facilities for their acceptability for use in the NRC operator licensing examination, is reviewed in detail in a panel session later in this meeting and will not be discussed here.

Adaptation of SAT for NRC

The goal of the first effort in this program was to examine and adapt the SAT process in order to provide a framework for NRC to evaluate industry programs for operator qualifications and training. Although there was an extensive body of literature, primarily from military and aerospace applications, on the design and development of training program using the Instructional Systems Development (ISD) or SAT processes, there was considerably less available on the evaluation of the effectiveness of these programs, particularly as applied to a civilian, regulated industry. The existing SAT literature was re-examined, and with the input of industry and NRC representatives provided during two project working meetings, a high-level "model" of the SAT for use in the nuclear industry was outlined to serve as the desired framework for NRC evaluation. That model is depicted in Fig. 1. It is compatible with the ISD-based model developed by the Institute for Nuclear Power Operations (INPO), [15] with the additional emphasis that training requirements are derived from personnel performance requirements, which in turn are derived from system requirements identified in a front-end systems analysis.

Following this high-level model, twelve checklists were proposed with rating scales for NRC to use to evaluate each of the major elements of the process. The checklists developed are listed in Table 1. It is important to note that these proposed checklists have not been field tested or evaluated by end users for practicality, acceptability, or utility. Such evaluation is necessary prior to full implementation, and would likely result in modification of content and/or approach.

TABLE 1. Proposed Checklists for Evaluation of SAT-Based Training System

Job and Task Analysis Checklist
Job Performance Measure Checklist
Training Objectives Checklist
Instructional Delivery System
- Instruction Guide Checklist
- Media Selection Checklist

Training Evaluation
- Internal Evaluation Checklist-Criterion Test
- Internal Evaluation Checklist-Student and Instructor Evaluations
- Internal Evaluation Checklist-Supervisor Evaluation
- External Evaluation Checklist-Supervisor Evaluation
- External Evaluation Checklist-Review of Operational Data
- External Evaluation Checklist-Structured Questionnaires for Evaluating Training
- External Evaluation Checklist-Review of Licensing Exam Results

The results of this initial effort were documented in NUREG/CR-3414. [16] Included in that report are two other results produced during the course of development of the model and checklists: (a) preliminary identification of key variables (performance shaping factors) to be considered in NPP control room personnel qualifications and training, and (b) an illustrative media selection model that might be used in the development of an instructional delivery system for NPP control room operators.

Malfunction Rating Scheme

A separate but related task carried out early in this program was the development of a technique that can be used to rank possible plant malfunctions as to their importance to training, in particular, to simulator training. The ranking scheme is compatible with a fully implemented SAT-based training system, but is designed using subjective scales so that it could be used in the iterim before complete and comprehensive data are compiled. Potential plant malfunctions are rated along three dimensions: consequence, frequency of occurrence, and difficulty of operator response. These parallel the difficulty, importance, and frequency (DIF) criteria commonly used in SAT development. The key elements of the ranking scheme are highlighted in Table 2. Malfunctions would be considered important for training due to a high rating on any of the three categories or a combination of the three. The details of the ranking scheme and an illustrative demonstration of its application to a specific plant are described in Ref. 17. Also included in Ref. 17 is a description of how the malfunction rating process would be incorporated into the overall SAT design process.

TABLE 2. Highlights of Malfunction Ranking Scheme

Consequences:	Malfunctions given a numerical rating of 1-15 depending on the consequences, (primarily implication for public safety) of the malfunction; ranges from relatively minor technical specifications violations to Condition IV events.
Frequency:	Based on actual operating experience and predicted frequency of occurrence; consider plant-specific and similar plants; consider different operating modes; rating values from 1-10.
Difficulty:	Based on system/task analysis data and expert judgement; rates relative difficulty on 7-point scale due to: (1) perceptual loading • searching and receiving information • locating and identifying objects (2) cognitive loading • information processing • problem solving and decision making (3) communication loading • communication type • communication context (4) motor action loading (5) time factor loading

A Task Sorting Procedure

During the implementation of a systems approach to training, a variety of analyses must be performed which require the subjective expertise of a training developer. One major analysis is the determination of where (i.e., in what setting, training category, etc.) individual job tasks should be trained and how they should be ranked relative to different instructional aids and approaches. Depending on the skill of the personnel making the decisions, the resulting allocation of tasks to training strategies may or may not be made properly. In the SAT, the kinds of courseware developed, the media and methods used, and the types of student evaluations performed are directly influenced by the general training strategy. Thus there is a "ripple effect" from poor decisions which have been made early in the process. For the NRC, faced with evaluating many different training programs, it becomes important to have an objective basis to determine whether industry selections are reasonable within the SAT framework.

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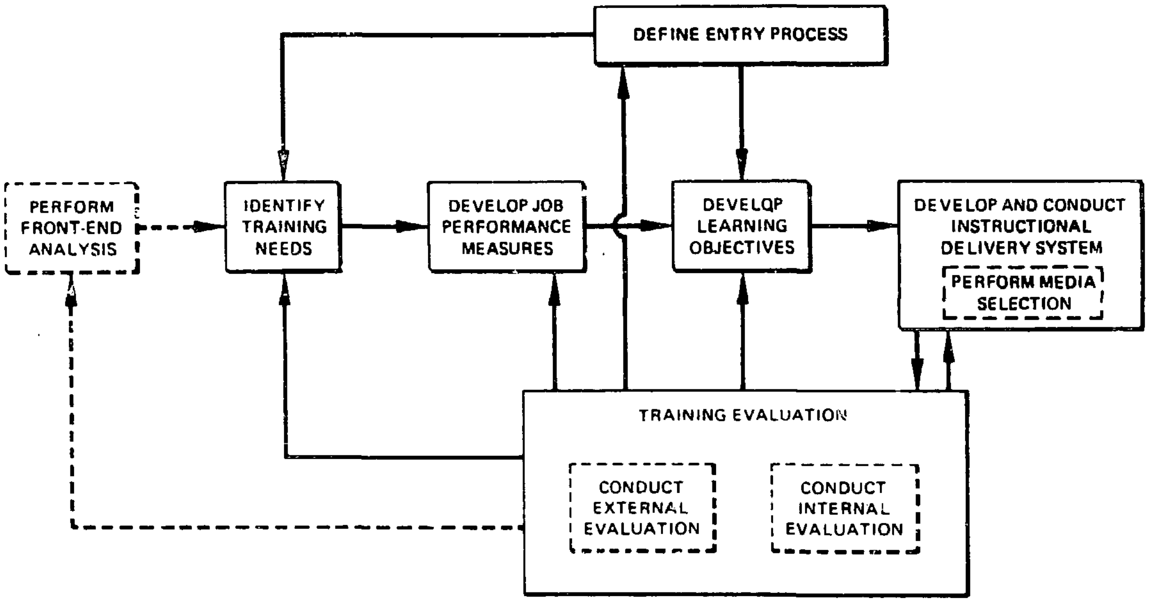

Figure 1. SAT structure for use in evaluating NPP training systems.

A task sorting routine (TSORT) [18] was developed to determine which training strategy should be applied to a given task. It accomplishes this by sorting tasks into nine categories: qualification, certification and refresher training, candidate for more or less training, potential simulator or formal training task, and candidate for on-the-job training or for elimination from training. Each category is defined along ten dimensions:

(1) skill acquisition difficulty
(2) skill performance difficulty
(3) immediate performance need
(4) safety consequences
(5) previous nuclear experience
(6) normal operation performance
(7) emergency operation performance
(8) plant delay tolerance
(9) regulatory requirement
(10) economic consequences

TSORT provides rank-ordered preferences for task allocation between and within categories. The ability to estimate a dollar loss incurred through failure to train on a task is included. A realistic economic model was beyond the scope of the work, but could readily be incorporated. The sort procedure is programmed for an IBM personal computer, menu-driven, and fully interactive for both data entry and analyses.

A Task Analysis Profiling System

Task analysis is generally a highly subjective process that draws on observations of job performers' behaviors and combines them with an analyst's expert knowledge of systems to produce a functionally useful set of skills, knowledge, abilities, and attitudes (SKAA). The procedure often winds up being an art rather than a science and, as a result, is subject to a variety of shortfalls characteristic of highly subjective procedures.

Because task analysis is used for a variety of research purposes, including courseware development, entry level skill identification, performance standards development, and personnel selection, large variations in task analysis quality can be very costly in time and resources. Unanticipated costs often occur as a result of repeated site visits to extract missed information, correct erroneous assumptions, or modify incorrect courseware materials. The end result is growing pressure for a faster, more economical method to support training research.

A task analysis profiling system (TAPS) [19] has been designed to remedy these problems. It draws on artificial intelligence concepts of pattern matching to provide an automated task analysis of normal English descriptions of job behaviors.

Definition of SKAAs. To support the automation of task analysis, a much more precise method for the definition of SKAAs than currently exists had to be created. For example, a definition of a human ability such as "perceptual speed" has generally relied upon text descriptions and the opinion of a task analyst such as the following:

"The ability to compare sensory patterns quickly in order to determine identity or similarity."

Although appearing easy to use, such a general definition can lead to a great deal of disagreement over what constitutes a perceptual speed instance. For example, it may be understood that perceptual speed is a visual ability combined with a cognitive activity of recognition or recall. It is not clear, however, if the "sensory patterns" could also refer to other senses, e.g., auditory recognition of Morse code strings, or tactual recognition by a pilot of changes in g-forces. Thus, from the standpoint of an automated tool to identify perceptual speed, a more precise method of definition is needed. Mallamad, Levin, and Fleishman (1980) [20] recognized the same problem and proceduralized some ability definitions through a series of question/answer flow charts that eventually led to the identification of individual abilities. Unfortunately, such systems and efforts to automate them (e.g., Rossmeissel, Tillman, and Best, 1982) [21] place a tremendous resource demand upon a user since each task must be scanned for each individual ability through a separate question/answer path. To apply such an approach to field analysis of SKAAs would quickly produce massive resource demands on the analyst that would outweigh the benefits of the faster, albeit "noisier" subjective approach.

TAPS has taken another approach in that it recognizes from the onset that resource demands on the user are a critical component in the ultimate implementability of a training research tool. The key to the success of the approach lies in its ability to define SKAAs in a flexible manner capable of accepting many different potential sentence variations of the same underlying idea. Thus, "rapidly spotting a change in a temperature gauge" or "detecting a panel meter deviation in less than ten seconds" must both be recognized as an instance of perceptual speed by the definitional rule.

TAPS gains this flexibility through an approach analogous to choosing dinner items from a Chinese menu. In a typical Chinese dinner, an acceptable "meal" is defined as picking one item from column A, one from column B, and one from column C:

		A	B	C
		Item 1	Item 1	Item 1
		Item 2	Item 2	Item 2
"meal"	=	Item 3		Item 3
		Item 4		

If item A4 was fried rice, item B1 was pepper steak, and item C2 was lychee, "meal" would be [fried rice, pepper steak, and lychee]; on the other hand, another perfectly acceptable instance of "meal" could have been [chicken chow mein, white rice, and sherbert] which would represent a different path through the columns. A similar logic may be applied to defining SKAAs. For example, another way to define perceptual speed could be:

	A	B	C
	Sees	In less than	Visual acuity test
	Hears	Before	
"perceptual speed"	Spots	In under	Auditory reaction time test
	Observes		
	Notices		

where one acceptable instance of perceptual speed is [spots, in less than].

If, as is the case in task analysis, the process is actually the reverse and one is presented with an instance which may represent perceptual speed embedded in other information such as:

"I must hear the change in charging pump frequency in less than 10 seconds."

then perceptual speed would be detected in the sentence by using a pattern recognition technique to spot the underlined word combinations and recognize that they correspond to an acceptable path through columns A and B. To go further, however, once perceptual speed is identified, the ability name in turn can function as a pattern that points to an acceptable performance test such as the "auditory reaction time test" in column C.

To accomplish the pattern matches it was helpful to develop rule processing procedures in a computer language suited to manipulation of sentence strings. Because of its ease of use and highly readable code, a simplified version of the LISP language called LOGO was used to initially code the procedures.

SKAA taxonomy development. Because readily usable SKAA lists did not exist in Chinese menu definition forms, they had to be generated. Existing taxonomies were surveyed and evaluated as to their usability. It soon became apparent that evaluative criteria for inclusion or exclusion had to be developed and in some cases (for example, cognitive skills) entirely new elements needed to be produced. To facilitate this process a model of skilled human performance was generated. The transformation of existing taxonomic elements into menu forms was accomplished in two steps. First, all available definitions were compiled for taxonomic items along with an analysis of key word patterns which occurred in the examples presented as definition instances. Second, key word patterns were subjected to a computerized thesaurus to find as many equivalent terms as possible. The resulting lists were then screened for applicability and entered into a structured data base. The result was a large set of menu definitions. Since the primary focus of TAPS was to quickly identify tests associated with entry level requirements of NPP operators, lists of usable measurement tests were generated for each ability and rank ordered by factor loadings. TAPS code was written so as to automatically reference these lists whenever a task analysis identified a particular ability as present. In order to illustrate the full potential of the technique, other types of lists were also generated for SKAAs. These lists allow the automated printing of applications, principles, potential safety risks, and even generate customized advice which could be used by an NRC training evaluator or industry training developer. Lists were developed for every taxonomic item; however, a rigorous compendium of human factors information was not attempted within the scope of this effort.

Figure 2 illustrates some of an actual output for a sample sentence that illustrates TAPS capabilities. At the top of the figure is the original sentence which shows errors in capitalization, punctuation, and includes technical abbreviations. The second sentence is the result of the first analysis step in which TAPS cleans up obvious errors and expands the abbreviations to their full length. Thus, HPCI becomes high pressure coolant injection, capitalization is normalized, and punctuation is removed. Although the example uses a single sentence, TAPS is not text limited, and works just as efficiently on paragraphs or even multiple pages of typed descriptions.

The original typed task was:

> Based on aBnOrmAl soNic PrOBE readings, iNfeR from NrC buLletins on CorrOSion thaT. HPci, safety Limits reQuire circuit bREaker MAiNteNAnce!

The TAPS expanded task used for computer analysis was:

> based on abnormal sonic probe readings infer from nuclear regulatory commission bulletins on corrosion that high pressure coolant injection safety limits require circuit breaker maintenance

Skill detected: diagnosis

*** some important principles are: ***

> Be particularly careful of this task if it involves maintenance, diagnostic skills can have wide individual differences.

Knowledge requirement for: reg. guides

> Relation of nuclear regulatory commission bulletins to plant operations. Literacy level for proper reading of nuclear regulatory commission bulletins.

Attitude detected: personal responsibility

*** points to consider and possible impacts are: ***

> This task probably involves unsupervised action, careless individuals may not be suited for it.
>
> Be alert for emotional situations that could impact safety such as marital problems.

Ability detected: deductive reasoning

*** some acceptable tests are: ***

> Complex deduction test #181
> Logical reasoning test #168

Figure 2. A sample excerpt from a TAPS sentence analysis.

TAPS systematically outputs skills and the information associated with them, knowledge, then attitudes, and finally abilities. The skill detected in Fig. 2 illustrates the ability of the program to serve as an automated source of guidance to a training developer by listing human factors insights associated with skill categories. "Knowledge" illustrates another capability of the program. After a general knowledge category such as "regulatory guides" was detected, the program retains specific information about the particular instance of regulatory guidance that was found. It then inserts the information into a sentence frame so as to produce customized textual material specific to the task being analyzed. The advice can be as detailed or general as desired, but only very simple principles are used in the present TAPS version. The detection of attitudes illustrates the capability of TAPS to use indirect clues. Since attitudes generally have to be inferred, TAPS recognized that the HPCI was a safety-related system and the the sentence was referring to maintenance behavior. Consequently, an individual's attitude toward "personal responsibility" could have a significant safety impact if maintenance was done unsupervised or in a slipshod fashion. Finally, the "deductive reasoning" ability illustrates that TAPS could be used to produce customized tests in real time.

Conclusion

What Has Been Accomplished?

The research and development summarized above has in many ways been representative of (and to some degree has influenced) the recent growth of human factors activities (in particular, the increased emphasis on training) in the nuclear power industry. Obviously, the single most significant event in relationship to human factors in this industry was the TMI-2 accident, though there certainly were some initiatives of major significance prior to March of 1979 (notably A. D. Swain's work in WASH-1400 [22] and Seminara's study for EPRI [23]). The pattern of human factors activities that has evolved is typical of human factors involvement in other technologies. The initial efforts typically are "needs identification studies" - surveys, assessment of current practice/capabilities, identification of problems, determination of needs (data, methods, modifications to design/practice, research, etc.). These studies are followed by applications efforts which apply existing technology, methods, and data, perhaps adapted from applications in other technological areas, to industry-specific problems. Finally, and hopefully in parallel, research and development programs are initiated to address the specific needs of the technology of interest (in this case, nuclear power). This technology-specific R&D then reaches the point of maturity at which it contributes to the advancement of the human factors field itself and will, in fact, spawn applications in other technologies.

The training related R&D summarized in this paper has followed this pattern. The early studies such as the assessment of sources of field data on operator actions (Ref. 1) and the surveys regarding simulator capabilities and usage (Refs. 7 and 8) are typical of needs identification studies. The efforts relating to task analysis (Refs. 10 and 11), training system evaluation (Ref. 16), and the malfunction ranking scheme (Ref. 17) are examples of applications and adaptation of existing techniques for industry-specific solutions.

Finally, the automated tools for training system development/evaluation (Refs. 18 and 19) represent nuclear-specific R&D which advances the state-of-the-art and has potential application to other technologies.

Without question, the fundamental accomplishment of the nuclear industry with regard to personnel training in the years since the TMI-2 event has been the adaptation and implementation of a systems approach to training. The comprehensive efforts of INPO in their Training System Development and Accreditation programs has been the dominant force in this essential movement. While NRC has currently postponed regulatory action related to training system requirements in order to permit time for the industry to fully implement INPO's accreditation program, the Commission's earlier activities and emphasis in this area (which certainly include the R&D described in this paper) also were a key factor.

What Needs To Be Done?

Given the virtually complete acceptance of the concepts and methods of the systems approach to training, what remains to be done? In particular, what are the R&D needs? If the accomplishments to date can be accurately generalized as "adaptation and implementation of a systems approach to training," the emphasis for the future might best be described as "training effectiveness evaluation."

While it is true that an essential ingredient of a systems approach to training is continued evaluation and feedback to the design process, this most crucial element often receives the least emphasis. It is also the element for which methodology and basic research data are least available.

The ultimate goal of training improvements, of course, is to improve performance on the job. However, the relationships between training system design elements and actual performance are not readily defined, much less quantified, and techniques for unobtrusive on-the-job measurement are difficult to devise. Methods are needed and institutional barriers will have to be overcome in order to even obtain data on in-plant job performance. Experience in ORNL's R&D program and numerous other programs in nuclear and non-nuclear technologies attest to the need for more basic R&D on human performance measurement, even in a more controlled environment. Little research exists to provide direct relationships between simulator fidelity and training effectiveness. Additional studies are needed on the relative effectiveness of various training media, especially advanced technology, for different kinds of tasks (or learning objectives). Basic questions of training program development, such as the optimum scheduling of retraining to enhance knowledge/skill retention require further study. The issue of effective team training (which should not be addressed outside of the context of control room design, crew workload, etc.) requires R&D support. Other special areas such as the impact of advanced control and display technology on training requirements, and effective training for extremely rare events (severe accident sequences) also need R&D support.

All of these issues, it seems, can generally be referred to as "training effectiveness" issues. In some cases, much information for the nuclear industry may still be gained by adaptation of R&D and existing technology in other areas - military, aerospace, etc. However, a significant R&D effort is still required for application to the nuclear industry, and in many areas, the state-of-the-art (or at least the publically available R&D base) in these other technologies is not appreciably advanced over that in the nuclear industry. Thus, it is apparent that a significant R&D effort in training effectiveness evaluation in the nuclear industry is required. Unfortunately, it is not apparent that such an effort is planned or even that the need for it is generally recognized.

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