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Nuclear Power Plant Simulators for Operator Licensing and Training

Part I - The Need for Plant-Reference Simulators
Part II - The Use of Plant-Reference Simulators

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ABSTRACT

Part I of this report presents technical justification for the use of plant-reference simulators in the licensing and training of nuclear power plant operators and examines alternatives to the use of plant-reference simulators. The technical rationale is based on research on the use of simulators in other industries, psychological learning and testing principles, expert opinion and user opinion. Strong technical justification exists for requiring plant-reference simulators for operator licensing purposes. Technical justification for the use of plant-reference simulators for operator training is less well grounded empirically, although expert opinion is that plant-reference simulators, when properly used, result in the most effective training. Part II discusses the central considerations in using plant-reference simulators for licensing examination of nuclear power plant operators and for incorporating simulators into nuclear power plant training programs. Recommendations are presented for the administration of simulator examinations in operator licensing that reflect the goal of maximizing both reliability and validity in the examination process. A series of organizational tasks that promote the acceptance, use, and effectiveness of simulator training as part of the onsite training program is delineated.

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NUCLEAR POWER PLANT SIMULATORS FOR OPERATOR LICENSING AND TRAINING

EXECUTIVE SUMMARY

The purpose of Part I: The Need for Plant-Reference Simulators is to provide technical information to the Nuclear Regulatory Commission (NRC) on the known efficacy of training simulators that can serve as the basis for possible regulatory action regarding simulator use in licensing and training. This is in response to a request by the Commissioners (SECY-82-232 of August 3, 1982).

The information-gathering techniques used to achieve the objectives of the project included:

- perusal of technical and research literature on the use of simulators for training and evaluation across several industries
- examination of the results of recent surveys conducted with nuclear power plant (NPP) operators, instructors, and licensing examiners regarding simulator use
- communication with acknowledged national experts in the area of simulator use, and the formation of a panel of experts, which was convened for a two-day meeting in January 1983.

Simulators and the Operator Licensing Examination

The use of simulators for conducting the licensing examination for reactor operators and senior reactor operators is currently required only at those NPPs that have plant-reference simulators (i.e., that essentially replicate that plant's control room in terms of physical appearance and functional performance). Based on the findings of our inquiry, the position is taken that a strong technical justification does exist for using plant-reference simulators for operator licensing purposes. The arguments for the use of simulators, and in particular plant-reference simulators, are:

- Because running emergency events on an operating nuclear power plant is not feasible, a simulator is a more valid means than written and/or oral examinations for testing a NPP operator's ability to carry out the perceptual, cognitive, communicative and motor skills necessary to mitigate emergency events.
- The directive to NRC staff to prepare procedures to assure near equivalency between licensing examinations where a plant-reference simulator element is included and where it is not (SECY-82-232) can at best be viewed as difficult to accomplish and from a testing perspective be viewed as impossible on theoretical grounds.

- Given that it is important to test in a full-task environment the ability of the NPP operator to apply knowledge regarding plant-specific information in a time-critical situation (i.e., an emergency event), licensing examinations given in a plant-reference simulator are more valid than those given using a generic (i.e., one that generally resembles the control room of a certain type of plant) simulator.

Simulators and Training Devices for Operator Training

In terms of the current status of research on simulators and training effectiveness, it is difficult to make an empirically-based statement concerning the use of simulators for NPP operator training. However, experts in the field of simulator use have no doubt about the superiority of the use of plant-reference simulators over generic simulators or other devices for achieving the most effective operator training possible. Their opinions are grounded in applications of psychological learning principles and in applicable training findings particularly from aeronautical training experience. Arguments for requiring plant-reference simulators in NPP operator training include:

- Analysis of operator tasks indicates that certain types of tasks require a plant-reference simulator for complete learning.

- Training on the plant itself is problematic in that (aside from economic considerations) many kinds of operations could not be safely practiced on the plant and there is the danger of damage to the plant.

- Feedback is needed for learning to take place, it is most effective when it is precise, and the most precise feedback comes from a high fidelity, plant-reference training device or simulator.

- Research and theory on transfer of training finds that the greatest opportunity for producing positive transfer occurs when the stimulus conditions and the response conditions between the training device or simulator and the actual equipment are equivalent.

- Although research on fidelity and training effectiveness does not indicate a need for high fidelity devices or simulators in the early stages of training or for training of procedures, expert opinion is that experienced operators, familiar with a specific control room, will benefit most from high fidelity, full-scope, plant-reference simulators for practice in discriminating and generalizing unforeseen emergency events, and such operators will exhibit greater user acceptance of a high fidelity plant-reference simulator.

- Nuclear power plant operators and instructors have expressed a desire for plant-reference simulators for training, and their views should be considered in making training device procurement decisions.

- Research indicates that team training is important in the development of team performance, especially for handling events for which probable consequences are hard to predict, and that such training is best done in a full-task, high-fidelity device after individual operator skills have been learned.

- The maintenance of complex operator skills requires much practice, which can be best achieved if each nuclear power plant has its own plant-reference simulator.

The purpose of Part II: The Use of Plant-Reference Simulators is to discuss the central considerations in the incorporation of simulators into licensing examination and training programs.

The Use of Simulators in Operator Licensing

Two central concerns in employee testing are that the examinations used be reliable (consistent across applications) and valid (measure what is supposed to be measured). Five recommendations are presented for the administration of simulator examinations in operator licensing that reflect the goal of maximizing both reliability and validity of the examination process:

- Use a core set of standardized scenarios that reflect important operator job skills in all plants.

- If necessary, also administer unique scenarios that reflect particular job skills required at a specific plant.

- Use a standardized procedure for administering simulator examinations.

- Use a standardized grading form or an objective measurement device, if available, for evaluating candidates on simulator exams.

- Train examiners on the administration of the simulator examination and the use of the grading form.

The Use of Simulators and Training Devices in Operator Training Programs

If a simulator is to be used efficiently and effectively as part of a training and requalification program at a nuclear power plant, its integration into the training program must be approached systematically. Based on an analysis of the use of training devices and simulators in the U.S. Air Force (Caro et al., 1980), a series of organizational tasks that promote the acceptance, use, and effectiveness of simulator training as part of the on-site training program is delineated:

- Develop a systems approach for the design of an integrated training program so that decisions regarding the use of the plant-reference simulator as one part of the training program are made in a logical fashion.

- Actively work to achieve instructor, operator, and management support for the simulator features and the use of the simulator, to improve procurement decisions and smooth the way for the introduction of the simulator into the training program.

- Structure and conduct the training in accordance with proven learning principles, to help assure effective simulator training.

- Carefully attend to the selection, training, and retraining of the simulator instructor and to the instructional support features to be built into the simulator.

- Design and prepare for an effectiveness evaluation of the training program, using professional assistance as needed.

- Develop activities that will reinforce the positive attitudes toward simulator training on the part of the instructors and management.

- Assure the continuing effectiveness of the simulator training program by being prepared to solve the problems of changes in training requirements, modifications to the nuclear power plant, inadequate maintenance support for the simulator, and deterioration in the quality of the training program.

PART I: THE NEED FOR PLANT-REFERENCE SIMULATORS

1. INTRODUCTION

Simulators have had a long history of use in the military and in aerospace applications (e.g., see Caro et al., 1980; Jones, 1979). More recently, simulators have been used increasingly by the ocean transport industry (e.g., Keegan, 1977; Hammell et al., 1980), by process control technologies such as the chemical processing industry (e.g., Marshall and Shepherd, 1977; Shepherd, 1977), and by the electric power industry (e.g., Hickey, 1981). Although simulators have widespread use, there are gaps in the research literature regarding how simulators can best be used and what kind of simulators can be used for maximum training effectiveness. In response to this, various work groups (AGARD, 1980; Hays, 1981) have been convened to discuss simulator research needs for the military, and the National Research Council's Committee on Human Factors recently formed a Working Group on Simulation to provide recommendations on research needs for improving the state of knowledge and practices of simulation design and use for many industries.

With programmatic research on the use of simulators in the nuclear industry only in the incipient stage, the preparation of a position on possible regulatory action regarding simulator use in such areas as nuclear power plant (NPP) operator training, licensing, and requalification necessitates a broad approach. The potential efficacy of the use of simulators in the nuclear industry can be assessed by analyzing the available literature, by analyzing operator tasks, by examining the opinions of those most likely to be involved with NPP training simulators (operators, instructors, and licensing examiners), and by discussing the issues with experts in the field of simulation.

1.1 Purpose and Objective

The purpose of this report is to provide a technical background to the NRC on simulator use as well as supporting information that can serve as the basis for possible regulatory action regarding simulator use in operator licensing and training. This project was started as the result of a request by the Commissioner (SECY-82-232 of August 3, 1982). The objective is to address the technical and practical justifications for the use of plant-reference simulators versus other alternatives for NPP operator licensing and training.

1.2 Scope and Method

Four major methods were used to achieve the objective of this project:

- a computerized literature search of technical and research literature pertaining to the use of simulators for training, performance evaluation, and licensing

- a manual literature search guided by documents located by the computerized search and by telephone requests to knowledgeable individuals for particularly pertinent or recent work and for already completed literature searches

- investigation of the opinions of operators, instructors, and licensing examiners regarding simulator use

- identification of acknowledged national experts in the area of simulator use and the formation of a formal panel of experts, whose purpose was to provide opinion on the need for plant-reference simulators in the nuclear industry and to review this document for technical accuracy.

A two-day meeting of the panel of experts was held in Denver on January 21-22, 1983. Suggestions, conclusions, and recommendations from the panel are presented, where appropriate, throughout this report. A list of the members of this panel and a chronological description of the proceedings of the meeting are found in Appendix A and B, respectively, of this report.

2. BACKGROUND AND DEFINITIONS

2.1 Possible Use of Simulators in the Nuclear Industry

A NPP simulator or training device could have many uses. These uses include, for example:

- operator selection
- initial operator training
- operator requalification training
- crew coordination training
- operator licensing examination by the NRC
- operator performance evaluation by the licensee
- nonlicensed operator training/familiarization
- management familiarization with operations
- assessing control room design changes
- testing of surveillance concepts
- testing and qualification of operator information systems
- instructors' uses for curriculum planning
- procedures development and testing.

Traditionally, NPP simulators have been used (NUREG/CR-1750) for initial operator training, operator requalification training, and operator licensing by the NRC. More recently, simulators have been used for emergency operating procedures development and testing (see NUREG-0899). In addition, Jones and Eschenbrenner (1982) have discussed how a NPP simulator can be used for operator selection purposes. However, because of the objective of this report and because the two most likely areas for regulatory action regarding simulators and training devices are in operator training (both initial training and requalification training) and in operator licensing examinations, these are the only two areas explored fully in this report.

2.2 Number of Simulators in the Nuclear Industry

As of April 1983, there were approximately 75 operating NPPs in the U.S. Of these 75 plants, 14 had plant-reference simulators, 26 had plant-reference simulators being built, and 6 had announced their intention to order a plant-reference simulator. The remaining 29 plants did not have a plant-reference simulator and had not announced an intention to build one. In addition, there were approximately 65 NPPs under construction. Of these 65 plants, 21 already had a plant-reference simulator, 31 were getting a plant-reference simulator, and 14 had not announced their intention to order a plant-reference simulator.

2.3 Definitions

The purpose of this section is to define plant-reference simulators, generic simulators, training devices, scope, and fidelity.

2.3.1 Simulators and Training Devices

Common usage of the term simulator in the nuclear industry has come to include both what we shall term "generic" simulators and "plant-reference" simulators, also referred to as "replicate" or "site-specific" simulators. Plant-reference simulators are those devices that meet ANSI/ANS 3.5 (1981), that is, they copy a specific NPP's control room, in terms of both physical appearance and functional performance. Thus, for our purposes the terms replicate simulator, site-specific simulator, and plant-reference simulator are interchangeable. Generic simulators are those devices that are a full-scale control room configuration, but that differ somewhat in physical appearance and functional performance from a given plant whose operators train on that simulator. The Babcock & Wilcox (B&W) simulator, for example, is a generic simulator for the Oconee units and TMI units. The term training device will be used to designate any device other than a simulator that is used for training purposes, such as random access slide projectors, photographic mock-ups, principles trainers, and part-scope trainers.

It is important to note that these definitions for simulator and training devices are not consistent with military and commercial aviation usage. In these industries, "training device" is a generic term that includes simulators. However, only a so-called plant-reference simulator would be considered a simulator, while the generic simulator would be considered a (non-simulator) training device. This is consistent with a strict definition of simulator that refers to a device that is as close to an exact copy of the relevant equipment as possible. However, we will use the terms plant-reference simulator and generic simulator because of familiarity to the intended audience, and we will use simulator and training device as mutually exclusive terms for ease of use throughout this report.

2.3.2 Scope

Scope will be used to refer to how many of the systems, subsystems, and components located in a NPP control room and used by an operator are modeled on a simulator or training device. Because the systems, subsystems, and components are located on control/display panels in a control room, the term scope can also be discussed in terms of how many of the control/display panels are modeled, including both main control room control/display panels and control room back panels. Determination of which panels need to be modeled is made through an analysis of licensing and training needs. Thus, a full-scope device has all of the systems, subsystems, components, etc. represented that are needed for operator training and/or licensing purposes, but this would not necessarily mean that the whole control room would have to be represented. By our definition, a simulator is a full-scope device, while training devices are part-scope devices.

2.3.3 Fidelity

Fidelity is used to denote the degree of similarity between a simulator or training device and the equipment that is being simulated. At this time the definition(s) of fidelity and even the use of the term fidelity is a debated issue in the field of simulation (e.g., Erwin, 1978; Hays, 1981; Caro, in Appendix C). The debate can be generally summarized by presenting the two major perspectives regarding fidelity. One is that fidelity is not a useful concept (or is a harmful concept) because it places too much emphasis on definitional and fidelity measurement issues at the expense of specifying device requirements on the basis of training objectives and psychological principles. A majority of the panel of experts formed in conjunction with this project generally expressed this opinion. Those taking the other perspective (including some members of the panel) would argue that no one would deny the need for specifying training objectives and for incorporating psychological principles regarding learning and performance into a device. However, the term fidelity is still used (often inconsistently), and if it is going to be used, then the whole field would benefit from useful and consistent definitions. Defining fidelity requirements is very important from a simulator procurement perspective. That is, the more exactly the fidelity requirements can be specified, the easier it is for the manufacturers to bid on the project and the easier it is for the purchaser to judge the ability of the simulator to meet the simulator specifications in the procurement contract.

The position taken in this report is a synthesis. That is, because the term fidelity has to be used in this report, then it should be defined. However, because ordering a "medium fidelity" simulator has little to no meaning to a simulator manufacturer, what is important is how the definition is operationalized (e.g., equating low fidelity with drawings or photographic mock-ups) and how training and licensing needs are related to the operational definitions. In the remainder of this section, the debate over fidelity definition issues will be briefly discussed and two terms--physical fidelity and functional fidelity--accepted for further usage.

The definitions for fidelity, as they apply to NPP simulators, are numerous. In analyzing the use of the term "fidelity," Hays (1980; 1981) outlined four separate ways that fidelity has been defined, albeit under different terms:

- physical fidelity - the degree to which the simulator reproduces the physical appearance and the control "feel" (typically kinesthetic feedback) of the operational equipment

- <u>functional fidelity</u> - the degree to which the simulator reproduces informational (stimulus and response) options of the operational equipment

- <u>behavioral fidelity</u> - the degree to which the simulator reproduces the tasks performed on the actual equipment

- <u>psychological fidelity</u>

No one definition is given for psychological fidelity, because the definitions have been diverse. Psychological fidelity has been used to designate:

- the degree to which the trainee perceives the simulator to be like the actual equipment (Kinkade and Wheaton, 1972)

- the composite of functional and physical fidelity (Fink and Shriver, 1978)

- the degree to which the simulator exercises the cognitive skills that are required in performing the actual job (Hughes Aircraft Corporation, 1980).

Our suggestion is that psychological fidelity is not a useful concept. If it is merely the composite of physical and functional fidelity, then it is not needed. Also, differences in trainee perception between a simulator and actual equipment have to be stated in physical or functional terms. The statement that "It just does not seem like the actual equipment" is not useful. Finally, if the simulator is physically and functionally like the actual equipment, then it should also exercise the cognitive skills that are required in performing the actual job as well as, more generally, reproduce the tasks that are performed on the actual equipment.

Thus, we agree with Hays' (1980) position that fidelity can be conceived of as a two-dimensional concept. He proposed the following definition (p. 9):

> Fidelity is the degree of similarity between the simulator and the equipment which is simulated. It is a measurement of the physical characteristics of the simulator (physical fidelity) and the information or stimulus and response options of the equipment (functional fidelity).

This two-dimensional definition has several advantages. First, the two dimensions relate to aspects of the simulator and not to behaviors or cognitions, although this would, of course, be considered a drawback by those who ascribe to psychological or behavioral fidelity as being important to achieve. Second, both types of fidelity can be operationally defined and measured. For example, Baum et al. (1982), suggest the use of the Panel Layout Index to measure physical similarity (Fowler et al., 1968) and the Display Evaluation Index to measure functional similarity (Siegel et al., 1962) of the simulator to the actual operational equipment.

In addition, the American Nuclear Society standards (ANSI/ANS-3.5, 1981) deal with physical and functional fidelity. The guideline for physical fidelity is that the simulator look exactly like the plant control room. The guidelines for functional similarity are: (a) the simulator values for critical parameters during steady-state operation should be within ± 2% with the reference plant parameters; (b) the simulator values for noncritical plant parameters for steady-state operation should be within ± 10% or should not detract from training; and (c) the simulator values for plant parameters for emergency events should move in the same direction as the reference plant parameters.

3. BASIC TASKS OF THE CONTROL ROOM OPERATOR

Before we examine what an operator does in a NPP, we first need to present two models of human performance. These models use terms that are needed for unifying various statements about operator tasks and for the discussion on fidelity research issues.

3.1 Two Models of Human Performance

One model of human performance is based on human information processing and responding. Baum et al. (1981), offer a widely-accepted trichotomized categorization adapted from Fitts and Posner (1967), which includes sensory/perceptual, cognitive, and motor performance. Some (NUREG/CR-1750) add a fourth category--communicating--which, in the three-category model, would be subsumed under cognitive or motor functioning, depending upon one's theoretical bias. We believe that adding communications as a fourth category of human functioning is useful because it incorporates a social interaction perspective that is not present with the other types of motor responses in which the operator is involved (e.g., valve control manipulation), which are generally perceptual motor responses. Thus, our first model involves four categories of human performance:

- sensory/perceptual performance - involves information input from outside the human
- cognitive performance - involves internal information processing, including storage in and retrieval from memory, information synthesis, and decision making
- communicative performance - involves verbal interactions
- motor performance - involves observable motor responses.

The second model relates to levels of human performance required in a control room. A widely-accepted model in the nuclear industry has been proposed by Rasmussen (see Rasmussen and Lind, 1982). This model differentiates among skill-based, rule-based, and knowledge-based performance.

- Skill-based performance - refers to highly automated, well-conditioned stimulus-response behavior that involves a minimum of conscious control. A good example is riding a bicycle (after one has become proficient at it).
- Rule-based performance - refers to performance that involves the recognition of specific, well-defined situations (stimuli) and the ability to apply proper rules or procedures to those situations. Procedural tasks provide a good example.

- Knowledge-based performance - refers to performance where well-defined stimulus-response relationships, as are found for skill-based or rule-based performance, are not known. In this case, the operator has to input and process information and generate a plan of response in a situation that he has not previously encountered.

From a reaction time perspective (the time it takes between receiving the stimuli and executing the response), skill-based performance can be executed most quickly. However, the highest level of "understanding" is exhibited under knowledge-based performance. Often a purpose of training is to get an operator to understand principles, etc., from a knowledge-based perspective and then to move that performance to rule-based and possibly then to skill-based (e.g., Christensen, 1982), depending upon the task.

While the Rasmussen and Lind (1982) model is concerned mainly with the amount of cognitive processing needed to carry out a task, there are other types of overlap between the two models. First, skill-based, rule-based, and knowledge-based performance all involve perceptual performance and motor performance, as well as cognitive performance. Second, while skill-based performance involves little, if any, cognitive processing, cognitive processing is the most important aspect of knowledge-based performance and forms an important aspect of rule-based performance. Finally, although communications may be needed for each type of performance, communications are probably most important regarding knowledge-based performance followed by rule-based performance.

3.2 Basic Operator Tasks

The purpose of this section is to discuss, at a general level, what an operator does in the control room and how this relates to the two models of behavior presented in the preceding section. This information will serve as a basis for the discussion of operator licensing examination needs in Section 4.

Jones and Eschenbrenner (1982) listed six general characteristics of the operator's job:

- vigilance
- decision making
- distribution of physical and mental workload
- teamwork
- data use
- balancing public health and safety concerns with plant availability concerns.

Vigilance is required under routine operations, say, at full power, when the operators spend long periods of time monitoring plant status from meters, recorders, displays, and readouts. Vigilance is particularly hard to train, and in many cases vigilance can best be improved through the installation of automatic sensors or through the redesign of equipment (e.g., using out-of-tolerance indications on the displays). The monitoring aspect of the vigilance task requires perceptual skills and cognitive skills. Viewed in terms of human performance requirements (Rasmussen and Lind, 1982), this monitoring of system parameters starts out as rule-based behavior. Hodges (1976, p. 5) notes that, "With experience, this [monitoring] becomes almost instinctual, scanning without discrete thought but instantly noting variations from the normal." Thus, while such monitoring starts out as rule-based performance (e.g., reactor vessel pressure is out-of-tolerance during normal operation if it is not between x psig and y psig), it can become skill-based performance.

Decision-making is a cognitive task. The operators must diagnose and correct plant disturbances using a myriad of inputs (e.g., annunciators, control panel displays, and safety parameter display systems), detailed knowledge about plant systems and system interactions, current plant equipment and safety system status, and operating policies and procedures. Much of this operator functioning is rule-based, because it involves the use of procedures or set rules of operation. However, because of the complexities of nuclear operations, especially with regard to system interactions, specific rules cannot be predetermined for all operator responses, so knowledge-based cognitive functioning is required. This is especially likely to be true during unanticipated emergency events.

A third characteristic of the job deals with the distribution of the operator's physical and mental workload. As implied above, under normal full power operations, the operator's job can be very routine. However, the operator can undergo periods of high physical and mental workloads, such as during planned outages and while responding to an emergency event. High mental workload, especially during the response to an emergency event, is increased by the complexity of control/display panel layout, which is not yet optimized for human operation. All of these conditions lead to stress. High amounts of stress can particularly affect knowledge-based performance and, to a lesser degree, rule-based and skill-based performance.

A fourth characteristic of the operator's job is the need for teamwork. An operator must coordinate work with other operators, auxiliary operators, maintenance personnel, and test and calibration personnel, among others. The operator is the key communications person at the NPP. This requires supervisory, planning, and communication skills. While hard to classify, these are probably best conceived of as knowledge-based behaviors.

The fifth characteristic listed by Jones and Eschenbrenner (1982) is data use. That is, an operator must be able to comprehend and synthesize voluminous amounts of data, in the form of procedures, piping and instrumentation diagrams, computer-generated graphics and printouts, equipment diagrams, annunciators, status indicators, etc. This requires knowledge-based performance.

The sixth and final characteristic deals with operator effectiveness criteria. By this the authors refer to performance in any environment in which an operator must respond to public health and safety concerns as well as to plant availability concerns. This is one more way to add stress to the operator's job, especially during situations where the two criteria are in obvious conflict.

Hodges' (1976) description of operator tasks includes some of the Jones and Eschenbrenner (1982) characteristics, but it also includes other task descriptions that are relevant to this discussion. First, Hodges (1976) notes that an operator's work time is filled generally with routine and repetitive tasks that, taken in isolation, are not difficult to perform. Much of what an operator does is follow procedures (rule-based behavior). To follow the procedures, the operator must know how to use them correctly, be able to carry them out, and be willing to use them. Although much of the operator's tasks are routine, difficulties in performance arise when the operator must perform near simultaneous communications actions, troubleshooting actions, control actions designed to keep the reactor in a safe state, and data collection actions. These actions are required, for example, during an emergency event, and they involve all four types of human performance (sensory/perceptual, cognitive, communicative, and motor). In this case, the operator is required to carry out all four types of performance nearly simultaneously.

Hodges (1976) also states that the operator's job entails "coordinated manipulative tasks." These involve, for example, frequent set point adjustments of automatic controls and manual control of valves, pumps, etc. during startups and shutdowns. This requires mainly perceptual and motor performance, although some cognitive processing is also used. Hodges (1976, p. 6) sees the coordinated manipulative task to be very important:

> The operator must know the control board so intimately that the selection and use of the proper control at the proper time becomes <u>instinctive and immediate</u>. [Emphasis added.]

This implies that control board familiarity is so important that control manipulation should be practiced enough to make it skill-based performance. This has important implications for simulator requirements regarding operator training and operator licensing examinations.

Finally, Hodges (1976) maintains that an operator must operate from a large knowledge base. That is, the operator must be ". . . a bit of a physicist, nuclear engineer, instrument engineer, and water chemist" (p. 7). This adds to his cognitive requirements and means that the operator must be able to carry out diverse knowledge-based performance.

4. SIMULATORS AND THE OPERATOR LICENSING EXAMINATION

This section of the report addresses the question of whether a technical justification exists for requiring plant-reference NPP simulators for the operator licensing examination process. Relevant information comes from a variety of sources. These include testing considerations, licensing examiner opinion, and the opinion of the panel of experts. First, current practices regarding the use of simulators for examination purposes are described. Then issues associated with the above question are discussed.

4.1 Current Use of Simulators for Licensing Examinations

In the first quarter of 1981, all operator license candidates were required to pass a simulator examination to get their license. However, carrying out examinations on simulators that greatly differed from a specific plant proved to be an impossible task to the examiners. Consequently, in January 1982 the decision was made to give simulator examinations only to operators from plants that had "plant-specific" simulators. However, using the definitions in Section 2.3.1, the simulators that have been judged to be "plant-specific" for examination purposes are plant-reference in some cases and generic in other cases.

One outcome of this decision, of course, is that some operators are required to pass a simulator examination, in addition to an oral and a written examination, to be licensed, and other operators must only take the oral and written examination. Recognizing this as a possible problem, the Commissioners (SECY-82-232) have directed the NRC licensing staff to "Prepare procedures that assure near equivalency between examinations at plants with and without simulators."

However, developing a procedure for assuring test equivalency may be theoretically impossible. For one thing, administering two different types of tests jeopardizes test reliability.* Thus, even if both tests tested for the same kinds of performance, how they are administered would still affect test equivalency. Also, the type of examination that an examiner gives is dependent on the kinds of performance that are to be tested. As will be discussed in much greater detail in the next section, a simulator examination can be used to test sensory/perceptual performance and motor performance, among other types of performance. Oral and written exams test cognitive performance and some types of communicative performance, but they are not nearly as good for testing motor performance, especially, compared to a simulator exam. From this perspective, then, assuring test equivalency between licensing examinations that do and do not include a simulator is an impossible task.

Finally, we should note the current practice for simulator examinations in the airline industry. Pilots must now pass an aircraft-specific simulator examination to get their air carrier's license from the Federal Aviation Administration (FAA), if such a simulator is part of the approved training program. If such a simulator is not available for training, the examination is taken in the aircraft. Also, for any program the entire examination can be taken on the aircraft if the simulator is to be out of service for any prolonged period of time. Slight discrepancies between the aircraft-specific simulator and the aircraft are allowed. However, in these cases the pilot is then required to go to the actual aircraft and to discuss these differences. In some cases, a performance test may be required on the aircraft to prove that the pilot can operate the equipment that differs from that on the simulator.

4.2 The Simulator Examination as a Work Sample Test

The NRC simulator licensing exam can be viewed as a subset of "work sample" tests (i.e., a test that comprises samples of the actual work to be performed). Perhaps the most common example of a work sample test is the typing test administered to applicants for secretarial and typing positions. As such, the general findings about the utility of work sample tests may bear upon the use of simulator exams. As Guion (1965) points out in his classic book, Personnel Testing: "When one is looking for people who already have the skills needed to do the job rather than the mere aptitude for it, a work sample test may be most useful" (pp. 193-194). This quote emphasizes an important distinction in testing--tests as "signs" versus "samples." A test as a sign would be more appropriate for assessing who will become a good operator (e.g., who should be initially selected into the training program), whereas a test as a sample would be more appropriate for determining who is a good operator. Because the NRC exam is a major vehicle for determining whether or not an applicant obtains the operating license, the focus of the exam should certainly be on the test as a sample rather than a sign of behavior. This implies that a work sample test, such as a simulator exam, is appropriate.

A government manual written for measurement specialists specifies a number of conditions appropriate for work sample tests. These include (Plumlee, 1980, p. 3):

- The job description places substantial weight on skills such as . . . [psychomotor skills, sensory/perceptual skills, interpersonal skills, diagnostic skills, and nonverbal learning] . . .
- Reading skill is not important for successful job performance.
- Skill in carrying out a coordinated sequence of job steps is critical to successful job performance and such skills are required at entry . . .

The above conditions are generally true of the RO and SRO positions, except that average reading skills are needed to read procedures. Thus, a work sample test such as the simulator exam is again indicated.

The above arguments in favor of a work sample test, such as a simulator exam, being necessary in the NRC examination process is bolstered in part by a review of findings regarding the use of work sample tests. Robertson and Kandola (1982) recently reviewed the results obtained from over 60 validity studies involving work sample tests. Validity is the ability of a test to measure what it is supposed to measure. On the basis of the studies they reviewed and a comparison of these to studies reviewed earlier in Asher and Sciarrino (1974), they concluded that "excluding biographical data, psychomotor work sample tests produce better validities than any of the more conventional tests" (p. 173). (It should be noted that the NRC licensing process includes biographical data in the form of education and experience requirements for license eligibility.)

Now, let us generally evaluate the written and oral examinations. What kind of performance can the written examination test? Quite simply, it can only test cognitive and written communication performance. (Obviously, the test also evaluates one's perceptual ability as it regards written material, but this is a different type of perceptual ability than scanning indicators, etc.). The ability to communicate in writing is important, but it is not the same as the intrateam communication that is required during an emergency event.

What can the oral examination test? Again, this test is mostly of cognitive performance and, in this case, oral communications. However, this oral communication is with the examiner, not with other operating team members during an emergency event. Oral examinations are also used to determine whether an examinee knows the location of certain equipment in the plant, the location of displays and controls on the panels, the location of procedures, etc., and to determine, at a very superficial level, whether an examinee could use the equipment, displays, controls, procedures, etc. if called upon to do so. Thus, this examination, albeit superficially, attempts to get at perceptual (which display would you look at?) and motor functioning (show me where the equipment is, show me where you would go on the control panel to find that display/control, or show me how you would manipulate that control). However, the operators being examined are not asked to carry out these behaviors in a real-time, coordinated manner as is needed on the job. Certainly, the oral examination does not require them to carry out perceptual, cognitive, communicative, and motor functioning simultaneously or nearly simultaneously as they would have to during an emergency event.

A simulator examination can test for these types of performance. In fact, other than running certain events on an operating plant and having the operators respond, a simulator is the only method that can be used to test an operator's ability to carry out the perceptual, cognitive, communicative, and motor skills necessary to mitigate emergency events. This is in agreement with NUREG/CR-1750, where it is concluded that 14 operator skills and knowledges require a plant-specific (i.e., plant-reference simulator to achieve complete training, because it follows that the plant-specific simulator would also be needed for complete testing. Because emergency events cannot be run on an actual plant, a simulator, as an examination tool, is the only remaining answer.

Two other issues require discussion. First, Guion (1965) discusses disadvantages of work sample tests, including cost, space requirements, and scoring difficulties. With respect to cost, the key issue is whether the increase in validity expected by using plant-reference simulators outweighs the costs of the equipment. Space requirements for plant-reference simulators are likely a problem at nuclear power plants insofar as they are translated into cost requirements. Scoring as a problem is addressed in Part II of this report.

The second issue worth noting about work sample tests is the attitude of examinees toward the exam. Robertson and Kandola (1982) review several studies that assessed such attitudes. They found that attitudes toward work sample tests were generally positive and, where comparisons were made, were more positive than toward traditional paper and pencil tests. In fact, Cascio and Phillips (1979) found that the introduction of a work sample test corresponded with a reduction in turnover from 40% before the exam to 3% after the exam.

4.3 Plant-Reference versus Generic Simulator Examinations

Theoretical and empirical justification derived from other settings exists for including a work sample as part of the NRC examination process. The major question remaining is whether or not the literature on work sample tests can be used to assess the relative superiority, if any, of plant-reference simulators over generic simulators in the NRC examination process. Although no study has been conducted specifically to test this question, a strong inference can be made from existing research as to the superiority of plant-reference simulators for use as an examination tool. Specifically, as discussed previously, well designed work sample tests are effective because they sample the (job) behaviors of importance. Robertson and Kandola (1982) discuss the extent to which there is overlap between the content of the test and the content of the job (point-to-point correspondence). They review several studies that compare the validities of tests differing in point-to-point correspondence. For example, Giese (1949) compared a typing test (a work sample) with a paper-and-pencil clerical skills test with respect to their validity coefficients for predicting job proficiency of typists. The work sample test had a validity coefficient of 0.64, whereas the test with less point-to-point correspondence, the clerical skills test, had a validity coefficient of 0.41. The criterion (job) measure was performance ratings made by supervisors. [The validity coefficient measures the extent to which scores on the test are linearly related to scores on the criterion measure. A value of 0.0 indicates no relationship, and a value of 1.0 indicates a perfect positive relationship.] Several other studies reviewed by Robertson and Kandola reveal the same pattern. Although they call for additional research in which the relationship between point-to-point correspondence and validity is thoroughly examined, the evidence they present does not contradict the conclusion that there is a strong link between the extent of point-to-point correspondence in a test and the validity of that test. Thus, a plant-reference simulator exam is a more valid test than a generic simulator exam.

Although much is made about the evidence in the Robertson and Kandola (1982) article concerning point-to-point correspondence and test validity, it is important to note that the argument does not rest solely on this evidence. Sound professional industrial testing practices dictate that the examination be constructed on the basis of a thorough understanding of the job (usually obtained by a job analysis) and that it adequately represents the frequency and importance of the knowledges, skills, and abilities required on the job. The extent to which critical job requirements are not included and irrelevant ones are included in the exam will reduce the validity of the exam. For certain purposes (discussed at the beginning of this section), the best way of incorporating the relevant job requirements in the exam is to have the exam actually be a sample of the job *per se*. Thus, a well constructed work sample test is congruent with standard professional testing practices.

4.4 Licensing Examiner Opinions Regarding Plant-Reference Simulator Examinations

Licensing examiners' opinions are necessary for determining whether simulator examinations are important and whether they should be carried out on plant-reference simulators. Their opinions regarding simulator examinations were determined through the use of a survey questionnaire at a recent conference in Gatlinberg, Tennessee that was filled out by approximately 75% (53) of all licensing examiners (Saari et al., 1983).

First, 98% of the examiners responding agreed that the material covered on simulator exams is highly related to the job of operator. When asked to distribute 100 points among the three examination types (assuming the use of a plant-reference simulator for the simulator examination), the examiners gave an average of 40 points to the simulator examination, 37 points to the oral examination, and 23 points to the written examination. However, they also agreed that improved guidelines are needed on what to cover in such exams. In response to an open-ended question about what the exam should cover, 67% volunteered the response that the exams should cover abnormal and emergency operations, 50% volunteered that the exams should cover normal operations, and 21% volunteered that the exams should cover problem recognition and diagnosis (multiple volunteered responses were accepted).

Unfortunately, the licensing examiners were not asked whether a plant-reference simulator should be required for examination purposes. However, it is clear that they see the examination as very valid (i.e., related to the job of operator), place equal importance on the simulator exam and the oral exam and more importance on the simulator exam than the written exam, see the simulator exam as a way to test abnormal and emergency operations, and do not like to give simulator exams on simulators that are not plant-reference. The inference from this is that licensing examiners would be in favor of requiring simulator examinations if they were carried out on a plant-reference simulator.

4.5 Opinion of Instructors on Plant-Reference Simulator Examinations

The opinions of instructors of nuclear power plant operators also are relevant to the issue of the use of plant-reference simulators. In February of 1983, an NRC-organized workshop was held for utility personnel involved in training operator candidates. About 26% of the 200 attendees filled out a questionnaire which included questions to elicit the instructors' opinions about the use of simulators for licensing exams. Findings from the survey are summarized in Saari et al. (1983). Further computations of responses on the most relevant items are reported below.

A series of questions was asked that dealt with the validity of the simulator exam. Instructors were asked to agree or disagree with the statement, "The material typically covered on the simulator exam is highly related to the job of operator." Fifty-one percent of the instructors agreed with the statement, 10% disagreed, and the remaining 39% took a neutral position. Next they were asked to agree or disagree with the statement, "The simulator exam is the best examination for testing an operator's ability to handle emergency events." Ninety-four percent agreed, only 2% disagreed, and 4% took a neutral position. Then they were asked, "For the simulator exam, indicate the percent of time that you think should be spent on these three operational areas: major plant casualties, minor plant casualties, and normal plant evolution." On the average, the instructors believed that 26% of the exam should be on major plant casualties, 34% on minor plant casualties, and 40% on normal plant evolutions. A related question asked them to "Rate the relative value of the 3 parts of the exam [written, oral, and simulator] in terms of ability to assess who is qualified to become licensed." Of the 100 points that the instructors were asked to spread among the three exam types, 49 points were given to the simulator exam on the average, 29 were given to the oral exam, and 22 were given to the written exam. Fifty-seven percent of the instructors gave more weight to the simulator exam than the written and oral exams. Thus, the instructors thought that the simulator exam was a better assessment tool than the oral and written exams, whereas the examiners thought that the simulator and oral exams were of equal importance, but were more important than the written exam.

Finally, a question was asked about the type of simulator that should be used for the simulator exam. Instructors were asked to agree or disagree with the statement, "For examination purposes, it is not necessary that a simulator faithfully replicate the operation and physical appearance of the control room." Only 13% of the instructors agreed with the statement, while 77% disagreed and 10% were neutral.

In summary, the instructors surveyed believe that the simulator exam is a valid test, believe that it is the best way to evaluate an operator's ability to handle emergency events, believe that it is a better assessment tool than either the written or oral exam, and believe that the simulator exam should take place on a site-specific (i.e., plant-reference) simulator.

4.6 Opinion of the Panel of Experts on Plant-Reference Simulator Examinations

One major purpose of the meeting with the panel of experts was to get expert opinion on whether plant-reference simulators should be required for commercial nuclear power plants. Appendix B contains a summary of this meeting. The consensus opinion of the panel of experts was that plant-reference simulators should be required for the commercial nuclear utility industry. While plant-reference simulators were believed to be needed both for training and for operator licensing purposes, the panel believed that requiring a plant-reference simulator could best be approached from a licensing perspective. The panel's reasoning for requiring plant-reference simulators for examination purposes follows from an analysis of what job performance requirements need to be tested, expert opinion, and the opinion of examiners, instructors, and operators on the most valid and reliable manner to test required performance.

The panel stated that one first needs to look at what an operator does and what an operator needs to be tested on (such as was discussed in Section 3.2). Then one needs to determine the best way to test these areas (such as was discussed in Section 4.2). If the areas involve important sensory/perceptual performance, important motor performance, or the need to test operators in the full task environment, then a simulator exam is needed, unless the exam can be carried out on the actual equipment.

The panel also stressed that expert opinion and the opinion of examiners, instructors, and operators should be taken into account in determining examination type. The panel members themselves believed that plant-reference simulators should be used for the licensing examination process, except that some other provisions might need to be made for older, smaller plants. The opinions of examiners, instructors, and operators are also favorable to the use of plant-reference simulators for examination purposes.

4.7 Determination of Scope and Fidelity Requirements for Plant-Reference Simulators for Examination Purposes

If the NRC does decide to require plant-reference simulators for examination purposes, then the necessary scope and fidelity of the plant-reference simulator needs to be determined. It is quite possible that, for instance, not all of the back panels are needed and not all of the systems need to be represented in the simulator for examination purposes. Also, if a specific display were never needed for examination purposes, then the display might not have to be functional, or it might be permissible for it to be a different type of display (e.g., an analog display versus a digital readout), or it might even be omitted from the simulator for examination purposes.

4.8 Summary

This section approached the plant-reference simulator question from a licensing perspective. The need for a work sample test was established on the basis of test validity considerations and the operator's job performance requirements. It was concluded that perceptual performance and motor performance of an operator could not be tested adequately via written and oral examinations so that a work sample test is needed to test such performance. In addition, near simultaneous performance of perceptual, cognitive, communicative, and motor skills, such as are required to mitigate NPP emergency events, cannot be tested adequately via written and oral examinations. Such performance can be tested only in a full-task situation on a simulator. It was also concluded that such an evaluation would have to be done on a plant-reference simulator, because it is important to test a license candidate on perceptual, cognitive, and motor performances that are specific to the candidate's plant. License examiners believe that simulator examinations are important and would likely strongly support a requirement for plant-reference simulators for examination purposes. Finally, the panel of experts believed that plant-reference simulators should be required for licensing examination purposes, although some other provisions might need to be made for certain plants.

5. SIMULATORS AND TRAINING DEVICES FOR OPERATOR TRAINING

In this section of the report, the need for requiring training devices and simulators will be evaluated from an operator training perspective. First, we will present a brief summary on the use of simulators for training in the nuclear utility industry. Second, we will briefly review the literature on simulator and training device scope and fidelity issues as they relate to training effectiveness. Then, we will discuss operator opinions, instructor opinions, and the panel of experts' opinions on the need for plant-reference simulators for training purposes. Finally, we will discuss methods for determining fidelity and scope requirements for simulators and training devices for operator training.

5.1 The Use of Simulators and Training Devices in Operator Training

Currently, license candidates receive approximately 2 to 4 weeks of simulator training before certification and approximately 1 week of simulator training annually or biannually as part of the requalification program. Generic and site-specific (plant reference) simulators are used depending upon which type is available for a given plant (NUREG/CR-1750). The type of training done on the simulator has usually followed that suggested by the American Nuclear Society (ANSI/ANS-3.1, 1981). The Institute of Nuclear Power Operations has also issued guidelines for requalification training and evaluation that involve the use of simulators (INPO, 1980).

Following the Three Mile Island (TMI) accident, the NRC has proposed several regulations regarding simulator use. According to Hickey (1981), "If all of the proposed regulations were adopted, a typical one-unit nuclear power plant would require approximately 1,300 hours of simulator training per year." Thus, it is clear that the use of NPP simulators for operator training could expand significantly in the next few years as a result of industry and/or NRC initiatives.

The use of training devices, such as part-scope trainers and principles trainers, has increased over the past few years in the nuclear utility industry. Several papers at a recent conference discussed the use of such training devices in the industry (see Society for Applied Learning Technology, 1981). However, the use of such training devices is by no means widespread.

5.2 Simulator Training Effectiveness Evaluation

The concept of training effectiveness is considered to be very important when it comes to specifying training device and simulator needs and requirements within the context of the overall training program. That is, generally speaking, in designing a training program one should first ask the question, "What is it that I want the trainee to learn?" Then a determination is made as to how the trainees will be best taught (e.g., lecture, self-study, part-scope trainers, simulators, on-the-job training, or mixture of methods). Then, with regard to needed training devices and simulators, the correct level of scope and fidelity is chosen for each to meet the training effectiveness goals. Finally, an evaluation is made to determine whether the chosen training methods were effective, i.e., accomplished the training goals.

Baum et al. (1981) outlined three general methods for evaluating simulator training effectiveness. These are transfer of training experiments, expert ratings, and development of analytic models. Several different transfer of training paradigms exist, including the percent transfer measure (Micheli, 1972) and the transfer effectiveness ratio (TER) (Povenmire and Roscoe, 1971). The equations for both are provided below:

$$\text{Percent Transfer} = \frac{Z_{ns} - Z_s}{Z_{ns}} \times 100$$

$$\text{TER} = \frac{Z_{ns} - Z_s}{Z_p}$$

where: Z_{ns} = amount of time it takes the group with no simulator training to learn the task to criterion on the operational equipment

Z_s = amount of time it takes the group with simulator training to learn the task to criterion on the operational equipment

Z_p = amount of time that the simulator group practiced on the simulator

Note that the TER takes into account the amount of time spent practicing on the simulator, which makes it a more useful measure, whereas the percent transfer measure does not. However, such measures are not without problems (Rolfe and Caro, 1982). In addition, transfer effectiveness studies are rare. One reason for this is the length of time and dollar commitment that it would take to study transfer of training across different types of simulator, although such research is now being sponsored by the Army Research Institute (Hays, 1981). In addition, Gagné (1954) stated that transfer of training studies are difficult because of a lack of adequate criterion performance measures, and this is still true today.

However, an important distinction on types of transfer has been made by Hammerton (1977) in a discussion on transfer of training and simulation. He made the point that there are two main classes of transfer--"first shot" transfer and "savings" transfer. First-shot transfer deals with the question of how prior learning of Task A (e.g., learning to respond to an emergency event on a simulator) affects the initial performance of Task B (e.g., response to a similar emergency event on the actual plant). Savings transfer deals with the question of how much training time is saved on Task B by prior learning of Task A. Therefore, the algorithms provided above are for savings transfer. It is clear that first-shot transfer is of major interest in reactor operator training. That is, the training should be such that an operator can handle an emergency event the first time it is experienced on the actual plant.

Aerospace research, verbal learning research, and perceptual motor skill learning research provide some relevant findings and theoretical work on transfer of training (Sawyer et al., 1982). Baum et al. (1981) discuss the Skaggs-Robinson Hypothesis, which predicts a U-shaped transfer of training curve as the similarity between the training device and the operational equipment moves from high to medium to low. Thus, the hypothesis predicts that high similarity results in high transfer, medium similarity can result in negative transfer because of confounding effects, and low similarity results in essentially zero transfer. This hypothesis has received little empirical testing.

The Osgood (1949) transfer of training theory is discussed frequently and has received empirical testing. Osgood postulated that the degree and type of transfer of training was a function of both stimulus similarity and response similarity between the training device and the operational equipment. The model predicts that response changes have the most dramatic effect upon transfer. Positive transfer is greatest when there are both high stimulus similarity and high response similarity between the training device or simulator and the actual equipment (such as would be the case with a plant-reference simulator). Negative transfer is greatest when there is high stimulus similarity between the device and the equipment with antagonistic responses (i.e., similar stimuli require totally different responses). Negative transfer can also occur when there is high response similarity on the device and the equipment with dissimilar stimuli (i.e., totally different stimuli require approximately the same response), which could be the case between a generic simulator and a specific plant. Although Baum et al. (1981) state that the model has not held up well in predicting negative transfer, it has focused much of the transfer discussion on both stimulus and response issues.

Miller (1954) hypothesized a functional relationship between transfer of training and cost as a function of fidelity (see, for example, Piper, 1981). Essentially, Miller predicted that from low to high fidelity, transfer of training would be represented by an S-shaped curve and cost would be a positively accelerating curve, so that at some point on the fidelity dimension there would be a point of diminishing cost-effectiveness. While the model has some intuitive appeal, it has never been tested empirically and the general terms like high or low fidelity are not defined so as to be useful in making fidelity versus transfer of training decisions.

The above characterizations of training effectiveness or transfer effectiveness are quite narrow. Most training experts would agree that simulator training effectiveness is a product of numerous variables. Dr. Ed Jones, member of the panel of experts, offered a figure that shows the relationships between equipment design parameters, quality of use variables, and training effectiveness (see Figure 1). This figure indicates that equipment design parameters beyond scope determinations and physical and functional fidelity determinations are important in determining training effectiveness. These include the instructional features on the simulator, the performance measurement system, the timelines of simulator design changes, and the way that data inputs from sources other than the control display panel (e.g., radio contact with maintenance personnel) are incorporated into the design.

Even with a high fidelity, plant-reference simulator, highly effective training is not a certainty. Figure 1 indicates seven quality of use variables that affect training effectiveness. These include the training materials used, the training techniques employed, the quality of the procedures used, the number of hours spent on simulator training, how much training the simulator training instructor has received, the instructor's performance proficiency assessment of license candidates and requalification candidates, and the quality control employed for the training program.

In summary, the results of savings transfer effectiveness studies are rare because such studies are likely to be too costly, time-consuming and/or inconclusive to be useful in making training device and simulator fidelity and scope decisions for the nuclear utility industry. Although theories on transfer of training differ in some respects, they would all agree with the statement that the greatest chance for producing positive first-shot transfer and savings transfer would occur when the stimulus conditions and the response conditions between the training device or simulator and the actual equipment were equivalent. However, in the final evaluation, the effectiveness of simulator training is dependent upon much more than fidelity considerations. Numerous equipment design parameters and quality of simulator use variables ultimately affect simulator training effectiveness.

5.3 The Relationship of Fidelity to Training Effectiveness

Several studies have tried to relate the degree of simulator fidelity to training effectiveness or transfer effectiveness. In a review of the literature on the influence of fidelity on the simulation of pilot performance, Gerathewohl (1969) concluded that the amount of transfer expected to occur in flight simulators seemed to be proportional to the degree of fidelity provided. Fink and Shriver (1978) stated that there is widespread agreement that to be effective a training device needed to possess a high degree of functional fidelity. Hammerton (1977, p. 3) stated that, "There is . . . . ample evidence . . . . that elaborate simulation--including such refinements as projected scenery and multiple-axis cockpit motion--produce very good transfer indeed." He cited three technical reports to support this claim (Caro et al., 1975; Young et al., 1973; Douvillier et al., 1960). Thus, there is evidence that high fidelity is a sufficient condition for good transfer.

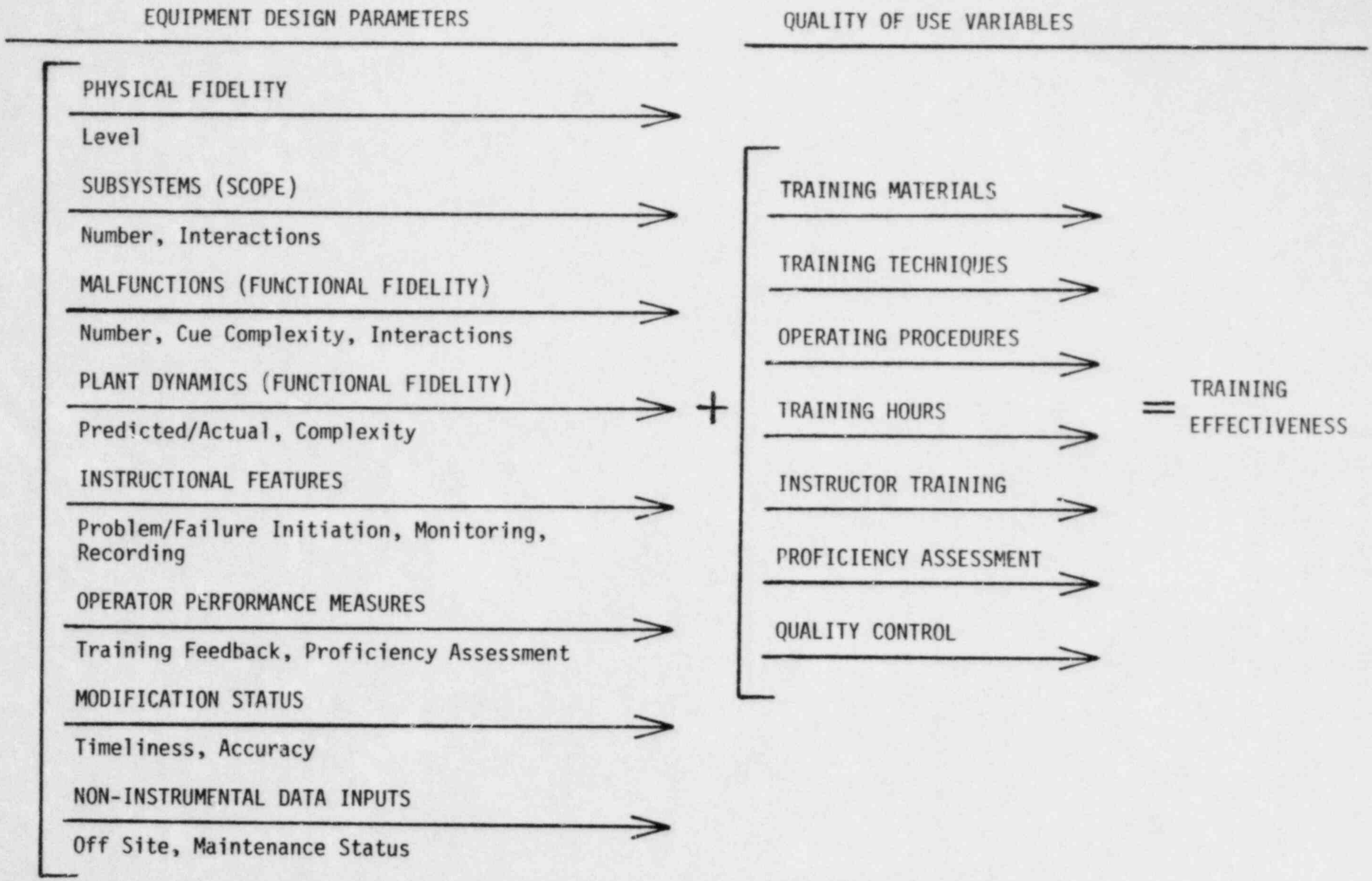

Figure 1. Simulator complexity, quality of use variables, and training effectiveness

The literature on the relationship of fidelity to specific types of human performance is now briefly examined. If there is one known fact regarding fidelity and transfer of training, it is that procedural tasks (rule-based performance) transfer as well from low fidelity training equipment as from high fidelity training equipment to operational equipment (see, for example, Grimsley, 1969; Johnson, 1981; Baum et al., 1981; NUREG/CR-2828). However, procedural skills will be forgotten unless practiced regularly (Baum et al., 1982). Thus, because most of NPP operations are procedural in nature, a high fidelity simulator is not needed for much of the procedures training. However, practice--either on some type of training device or on actual equipment--in using the procedures is needed. An important point made by the panel of experts was that just because a high fidelity device is not needed for procedures training, that does not mean that the device can differ greatly from the specific control room of interest. That is, a photographic mock-up of a control/display panel is a low fidelity device that can be used for procedures training, but the photograph should be of the actual control/display panel of interest (plant specific) and not of some "generic" panel.

A general statement can be made based on research regarding fidelity requirements for good transfer of training for procedural tasks; however, such is not the case for other types of performance. Skill-based and/or perceptual-motor responses have received some research in the military/aerospace industry as of late. A thorough theoretical discussion of the process of skill performance and its relationship to the design and use of training equipment has been presented by Spears (1982). Baum et al. (1981) state the following regarding such performance (p. 20):

> Perceptual-motor skills transfer less completely [than procedural skills] because they are most susceptible to imperfections in the simulation of dynamic factors of environmental fidelity such as motion, visual, and kinesthetic cues and control forces. Nevertheless, while the level of transfer may be lower, rapid adaptation appears to take place in the operational environment.

This suggests that high fidelity may not be required for perceptual-motor responses if the operator gets to carry out the response (practice it) in the control room. However, in a recent study on training effectiveness as a function of training device fidelity, Baum et al. (1982) found that high physical similarity on a perceptual-motor training task resulted in better performance on the transfer task than did low physical similarity on the training task. Also, it seems logical to suggest that if an important perceptual-motor response were needed during an emergency event, and the response could not be practiced on the operational equipment, then a high fidelity training device for the response would be more important than if the response could be practiced on the operational equipment.

While an operator's job is often procedural in nature (rule-based performance), an operator is still required to engage in knowledge-based (cognitive) performance, especially during an emergency event. Unfortunately, although such knowledge-based performance is directly relevant to the NRC's concern about protecting public health and safety, little research has been done on fidelity requirements for effectively training such performance. Several authors have hypothesized about this area, however. In NUREG/CR-2828 it is stated, for example, ". . . much of the procedural training . . . can be accomplished with low fidelity training. However, when system diagnosis decision making tasks are trained, higher fidelity levels will likely be required." Some research indicates that emergent events (such as unforeseen emergency events at NPPs) require increased fidelity (see Erwin, 1978). NUREG/CR-2828, which reports an analysis of NPP operator training on which to base recommendations concerning operator licensing, states (pp. 2-80):

> . . . it was determined that 14 RO [reactor operator] and SRO [senior reactor operator] skills and knowledges required a plant-specific simulator to achieve complete training. This determination was based on the initial assumption that in-plant training requiring plant manipulations could not be conducted . . . and that the classification of the skill or knowledge required . . . [perceptual, cognitive, motor, or communication] processes. . . .

An argument could be made that a high fidelity, plant-reference simulator would not be good at providing initial training for cognitive tasks because of lack of familiarization of the trainee with the equipment, lack of ability to screen out extraneous information, and inability to follow sequences of events in real time because of the speed with which they occur, although these problems could be overcome through training program considerations. The need for high fidelity, plant-reference simulators is much harder to refute, however, when discussing the training of experienced operators to handle emergency events that they have not yet experienced even on a simulator. Experienced operators are intimately familiar with the control room. What they need is practice in handling a varied set of emergency events in real time within the control room context (Christensen, 1982) that will provide them with discrimination training and generalization training (Johnson, 1975) for unforeseen emergency events. High fidelity, plant-reference simulators are needed for such training, especially if the variable of user acceptance/motivation is heavily weighted.

5.4 Team Training

Several independent reviews of research on team performance and team training have been carried out in recent years (Denson, 1981; Collins, 1977; Wagner et al., 1977; Hall and Rizzo, 1975; Knerr et al., 1979; Kribs et al., 1977). Reviewers have typically observed that it has been difficult to specify what it is about team performance that is more than a combination of individual member skills. One thing that has been suggested, however, is that intrateam communications are a distinguishing characteristic (Knerr et al., 1979; Wagner et al., 1977). The research that exists on training in team communications suggests that simulators are useful for training team communications and, more generally, team performance. Based on a review of training research, Knerr et al. (1979) hypothesized that tasks that are communication-oriented and tasks that are performed during an emergent event benefit from team training. An emergent event is one in which the probable consequences of certain actions cannot be predicted, such as certain NPP emergency events; knowledge-based performance will be necessary.

Wagner et al. (1977) suggest that the following general conclusions can be drawn from research on team performance and training (p. 17):

- Team training is a necessary addition to individual training for tasks that require interaction and other "team skills".
- Effective team training can occur only if the team members enter the training situation with the individual skill competencies that are needed.
- The team context is not the appropriate location for initial acquisition of skills by individuals.
- Performance feedback is critical to team as well as individual acquisition of skills.

This suggests that team training is needed and would be most useful late in the initial operator training phase and during requalification training. Also, team responses to emergency events would most likely benefit from team training. Such training could be done in a realistic fashion on a simulator only.

The need for realism (high fidelity) for team training has not received much study. In a review of the literature on team training, Wagner et al. (1977) noted that Briggs and his colleagues at the Naval Training Device Center had conducted a series of experiments from which one could conclude that the team training did not transfer well to the operational environment when the training simulation was of low fidelity. They observed that Briggs' studies were conducted only in established situations (all the tasks and activities were specified beforehand; thus rule-based performance is applicable). It would seem reasonable to hypothesize, however, that these studies suggest that high fidelity is needed for training team performance for emergent situations. Finally, there are numerous observations in the research literature that high-fidelity simulations used for team training, such as those for space missions or air defense operations, have been shown to be effective. Unfortunately, these simulation techniques provide little generality beyond the specific training mission (Wagner et al., 1977).

5.5 Performance Evaluation by the Licensee

Section 5.2 discussed the general determination of whether simulator training is effective. In this section we shall briefly discuss the need for the licensee to evaluate its license candidates and licensed operators.

The purpose of Section 4 was to discuss the need for a plant-reference simulator for the licensing examination process. The argument was presented that a work sample evaluation was the best method for determining whether a license candidate possesses certain types of necessary performance abilities. Obviously, the instructors at the NPPs should be as concerned about performance evaluation as the NRC. If certain types of performance are deemed important enough to require a simulator examination before receiving an operator's license, then these types of performance should also be important enough to require simulator training and performance evaluation on the simulator as part of the training program. However, in line with the panel of experts' reasoning that it is easier to justify a plant-reference simulator for licensing purposes than for training purposes, it is clear that if a plant-reference simulator exam were required, then the training staff would have more incentive to train and to evaluate their license candidates and operators on the simulator.

5.6 Operator Opinions on the Need for Plant-Reference Simulators

The worth of any training device or simulator is greatly affected by trainee acceptance. While trainee acceptance is dependent upon several factors (Mackie et al., 1972)--including instructor variables, trainee variables, instructional variables, and pattern of use variables--fidelity issues can also have a large effect. That is, if the trainee, especially if the trainee is a licensed operator, does not perceive the simulator to be like the actual equipment, his acceptance of the training device could be negatively affected. For example, Johnson (1981) believes that the realism of training undoubtedly influences the motivation of a trainee, and Saastamoinen (1976) believes that most systems need to be simulated in order to produce realism. Baum et al. (1981) theorize that user acceptance and motivation combine to influence simulator utilization, and state that utilization (p. 23) ". . . is the least well understood and, according to some, the most potent factor in determining training simulator training effectiveness." Thus, user acceptance needs to be considered in making decisions about simulators and training devices.

Operator opinions regarding the use of site-specific (i.e., plant-reference) and generic simulators for training purposes were sampled at an operator feedback workshop conducted for the NRC (Saari et al., 1983). Thirty-two people attended the workshop. While only half were operators and the other half were instructors or unit supervisors, the responses of the operators and the others did not differ substantially. The workshop participants unanimously agreed that a site-specific (i.e., plant-reference) simulator was the "only way to go" for training. Although they did not find generic simulators useless in training (such simulators allow one to go through the thought process for generic accidents), they also were concerned about some of the possible consequences of using them in training (operators having to learn where displays/controls are and then unlearn it when returning to own plant, operators not gaining full confidence in handling like situations on own plant, and simulators not being upgraded as plant changes). All believed that the problems experienced with generic simulators plus the lack of adequate training time on the generic simulator would be solved if their plant had a site-specific (i.e., plant-reference) simulator. The opinions of these operators parallel those expressed by other operators in discussions with PNL and the panel of experts. It is not unreasonable to expect that they would generalize to the full population of NPP operators.

5.7 Instructor Opinions on the Need for Plant-Reference Simulators

Two questions were asked on the survey handed out at the NRC-sponsored instructor's workshop (see Section 4.5) that are directly relevant to the question of the need for plant-reference simulators for operator training. First, the instructors were asked whether they agreed or disagreed with the following statement, "There is a strong need for more simulator training in our training program." Sixty-eight percent of the instructors agreed with the statement, 23% disagreed, and 9% took a neutral position. The second relevant statement that the operators were asked to agree or disagree with was, "I feel that my plant should have a site-specific simulator on which to train and evaluate the operators." Only 2% of the instructors took a neutral position on this statement, and the remainder (98%) agreed that their plant should have a site-specific simulator. In summary, the instructors very strongly believe that site-specific (i.e., plant-reference) simulators are needed for operator training and evaluation, and most believe that more simulator training is needed in their training program. While only 26% of the instructors attending the workshop returned their survey, these data provide a strong indication that instructors favor the use of plant-reference simulators.

5.8 Opinions of the Panel of Experts on the Need for Plant-Reference Simulators for Training

As discussed in Section 4.6, members of the panel of experts were unanimous in their agreement that plant-reference simulators should be required in the nuclear utility industry. While it was the panel's belief that regulating the procurement of plant-reference simulators was more easily justified from a regulatory position through the licensing process, the reasons that they gave for the need for plant-reference simulators dealt more with training issues and utility liability issues. Supporting observations are presented in the Caro papers in Appendix C. The reasons, presented in the discussion of the panel of experts meeting summary (Appendix B), are briefly summarized below.

- From a legal viewpoint, a utility will find itself in a more defensible position in the event of an accident involving a release of radiation if operator training has been performed on a plant-reference simulator than through other alternatives including generic simulators.

- Operator preference, deemed an important consideration in the decision, has been observed by several members of the panel to be in favor of plant-reference simulators for training.

- Approaching from a perspective of relative costs (e.g., the cost of a plant-reference simulator versus the cost of using the plant itself for training or examination), it is evident that savings with respect to that particular alternative can be realized quickly through the use of a plant-reference simulator.

- The acquisition by nuclear utilities of high potential, plant-reference simulators could plausibly become the impetus for increased efforts to improve further the level of training and attitudes toward training in the nuclear utility industry.

- A consideration of psychological learning principles indicates that plant-reference simulators, when properly used, will be more effective than other alternatives in some areas of training, such as for skill-based and knowledge-based behavior.

Whether implicit or explicit, the underlying concern in all of the above reasons is that the most effective training method be used. The informed opinion of the panel of experts was that plant-reference simulators, until and unless future research proves otherwise, are the most effective means for accomplishing operator training. Based on a knowledge of psychological principles and applied research experience with simulators, panel members also stated:

- Specific motor skills are better learned through doing than through cognitive practice (watching or thinking about) and skill-based behavior is best learned on a plant-reference simulator.

- Rule-based behavior (following procedures) can be learned on low-fidelity devices or simulators, but the cues must be plant specific.

- The development of knowledge-based behavior requires precise feedback.

- Plant-reference simulators can provide more precise feedback (knowledge of results) than can generic simulators; learning depends on feedback, and immediate and precise feedback is the most effective.

- The maintenance of complex, plant-specific skills requires considerable practice which, since it cannot feasibly take place on the plant, must take place on a plant-reference simulator.

- Negative transfer effects are an ever-present danger on generic simulators.

5.9 Determination of Fidelity Requirements for Training

As discussed earlier, simulators and training devices need not always be high fidelity, especially for procedural tasks, although it is important that they are plant-reference. If this is the case, then some method must be used to determine what level of fidelity is necessary for effective training for specific objectives. At least two methodologies are available; both are based upon a systems approach.

One method has been put forth by Cream et al. (1978). It involves the following steps:

- a detailed task analysis including a listing of subtasks
- for each subtask, a description of its sequencing, initiating, and termination conditions, operator actions required, and relevant displays and controls
- selection of the tasks to be trained by ranking each functional task and subtask along the three dimensions of criticality, frequency of performance, and difficulty of performance (C/F/D).

Criticality is assessed in terms of the consequences for not carrying out the task or for carrying it out incorrectly. Tasks and subtasks that are rated high on C/F/D are included in the training program. Then, fidelity decisions are made using mostly logic and best judgment, in that the

> . . . level of fidelity needed to accomplish specific tasks can be roughly estimated in terms of required cues and the required clarity of their presentation. The costs of obtaining various levels of fidelity can be discussed in terms of dollars, limitations in the state-of-the-art, and reliability difficulties. No rigorous decision-making procedures have been developed here. The factors in the cost/capability tradeoff are not easily quantified. (Cream et al., 1978, p. 149)

Baum et al. (1982) have developed a methodology for fidelity decisions, which also includes the use of logic and best judgment. Their method is also based on or done in parallel with a job/task analysis. When the fidelity specification phase is reached, it involves analysis of three types of variables (p. 17):

> A number of variables affect the judged level of device fidelity and the specification of fidelity, including those related to the (1) task(s) to be trained; (2) the actual equipment characteristics; and (3) the requirements/characteristics of the training environment and personnel.

For Baum's method, task variables that need to be considered include:

- task domain (operation, test, or maintenance)

- task type (sensory/perceptual, cognitive, or motor)

- task difficulty (unskilled, easy to perform, fairly hard to perform, or hard to perform)

- task frequency

- task criticality (delay tolerance and consequences of inadequate performance)

- task learning difficulty (easy, modestly difficult, difficult, or highly difficult)

- task practice requirements

- task required skills, abilities, and knowledges.

Actual equipment characteristics that affect fidelity decisions include physical and functional aspects of the equipment, as defined by Hays (1980). Training environment/personnel variables that must be considered in the fidelity requirements analysis include:

- existing or projected training program restraints

- device purpose

- instructional principles

- student population (e.g., aptitude, ability, and skill level)

- instructor population

- safety.

Again, there is no structured, established method for weighting these variables in a fidelity decision--the method is based on logic and informed judgment, but the variables that must be considered are expressly stated.

Both approaches can be useful in making decisions on minimum fidelity requirements for a training device or simulator. Such analyses are especially useful when increased fidelity is achievable only at greatly increased device cost. However, the drawbacks of low fidelity must also be considered. One major drawback may be decreased instructor and trainee acceptance, especially regarding a plant-reference simulator. Shepherd (1977) listed several effects that might occur from sacrificing fidelity. If the simulated display is much smaller than an actual display, the trainee could develop information-gathering strategies that do not transfer to the real situation. If the panel layout and instrument design are different on the simulator compared to the actual equipment, then any strategies regarding pattern recognition developed during training would not transfer or, worse, might negatively transfer from training to operation. If static simulation is used rather than allowing a temporal build-up of the symptom patterns, then the trainee will not be able to develop mitigation strategies based on rates of change of symptoms. Low fidelity simulators/trainers are often harder to upgrade in light of new plant data. Finally, it is easier to provide stress in the training situation if training is done on a high fidelity device. Related to these comments are those of the panel of experts. Their collective wisdom was, to paraphrase, "when in doubt, use plant-specific, high fidelity simulation."

5.10 Determination of Scope Requirements for Training

Two different types of scope questions need to be addressed. The first is related to the scope of a plant-reference simulator--i.e., which panels, back panels, systems, components, etc., should the plant-reference simulator contain? The second question deals with the need for training on part-scope trainers versus (full-scope) plant-reference simulators. This section deals with the second question and answers the question whether the NRC should consider regulatory action regarding part-scope trainers.

How does one make decisions regarding the use of part-scope trainers versus simulators? Theories of learning suggest, for example, that learning progresses from the simple to the complex, that learning benefits from a hands-on approach, that learning benefits from practice in meeting the initial learning criterion and that additional practice (overlearning) greatly slows forgetting, that learning benefits from immediate knowledge-of-results (feedback), and that learning benefits from distributed, as compared to massed, practice (Christensen, 1982). Part-scope trainers would be very useful in enhancing learning using the mentioned principles, especially for initial operator training. Kriessman (1981) believes that early training should begin on part-scope training devices and advanced training should progress to plant-reference simulators (p. 26).

> If the task is to train operators to increase the efficiency of operation . . . then a part task, training oriented simulator might be the most cost effective training tool. If the task is to license an operator on a highly critical, government-regulated process, then a replica simulator is often the only solution.

Hays (1980) discussed scope decisions in terms of stages of learning. It has been postulated that different levels of simulation (scope) are needed to bring a trainee along from, say, the new recruit through an auxiliary operator through reactor operator to senior reactor operator. Hays (1980) reviewed the work of Fink and Shriver (1978) and of Kinkade and Wheaton (1972). Both sets of authors agreed that it is most cost-effective to train the first stages of learning on part-scope trainers before moving to more expensive simulators for advanced trainees. Their more specific suggestions are presented in Tables 1 and 2.

Table 1. Relationships among stage of learning, training objective, and type of training device

Stage of Learning	Training Objective	Type of Training Device
First stage	Acquire enabling skills and knowledges	Demonstrators (films, TV, mock-ups, etc.) Nomenclature and parts location trainers
Second stage	Acquire uncoordinated skills and unapplied knowledges	Part-task trainers Procedures trainers
Third stage	Acquire coordinated skills and the ability to apply knowledges	Troubleshooting logic trainers Job segment trainers Skills trainers
Fourth stage	Acquire job proficiency in job setting	Operational equipment Actual equipment trainers

Source: Fink and Shriver (1978)

Table 2. Relationship between stage of learning and type of training device

Stage of Learning	Types of Training Device
Indoctrination	Films, TV, and mock-ups
Procedural training	Photographs and functional and nonfunctional mock-ups
Familiarization training	Functional equipment and part-task trainers
Skill training	Functional trainer with man-machine interfaces represented Part-scope trainer
Transition training	Part-scope simulator
Maintenance of performance proficiency	Part-scope simulator and full-scope simulator

Source: Kinkade and Wheaton (1972)

Although part-scope trainers may be useful in training programs, it is not clear that they are necessary if a plant-reference simulator is available. They are useful, for example, when on-the-job training time or full-scope simulator training time is at a premium (Fink and Shriver, 1978). The panel of experts also stated that the decisions regarding the need for part-scope trainers, principles trainers, etc., should be made on a different basis than the decision regarding purchase of a plant-reference simulator. Two different situations might warrant the need for part-scope trainers. First, as presented by Fink and Shriver (1978), part-scope trainers may be needed if training time on the simulator is limited. Second, as discussed by the panel of experts, specific tasks can be presented with higher fidelity on part-scope trainers than on plant-reference simulators in some cases. This may be needed to promote adequate learning progress, especially for very complex tasks.

One study has been carried out regarding the need to train on part-scope devices before training on simulators. Crosby et al. (1978) investigated the transfer of training from a low fidelity, part-scope simulator to a high fidelity, full-scope simulator, and subsequently to an aircraft. On their initial evaluation, the group that trained on the low fidelity device, compared to a control group that did not receive such training, performed significantly better when tested on or adapted more quickly to the high fidelity simulator. Once both of the groups had been trained on the high fidelity device, no differences in performance were found on the actual aircraft. The study results showed a considerable amount of positive transfer at the outset, but the initial performance differences disappeared after 1 month of academic training and high fidelity simulator experience.

5.11 Summary

Currently, NPP simulators are used very little for operator training and requalification purposes, but that could change dramatically in the future as a result of industry or NRC initiatives. Thus, it is important to determine whether and how training devices and simulators are needed for operator training/requalification purposes and how fidelity and scope decisions are made in light of this need. Training device and simulator needs are best viewed from a position of training effectiveness or transfer effectiveness. An analysis of the two major types of transfer--first-shot transfer and savings transfer--suggests that first-shot transfer is more relevant to some of the operator training needs, at least as it pertains to training for handling emergency events. Research suggests that for good first-shot transfer, high fidelity training devices or simulators are needed. In addition, all of the psychological theories on transfer would agree that good positive transfer (savings or first-shot) is most likely to occur when the training device or simulator is as much like the actual equipment as possible.

The research on training device or simulator fidelity and training effectiveness is in general agreement with this theoretical position.

Several researchers have reviewed experiments or carried out their own and have concluded that higher fidelity devices produce the most positive transfer. In the few situations where high fidelity appeared to be detrimental to learning (and hence transfer) the problems appeared to be the result of the training program, not the fidelity of the training device, per se.

If there is one well-researched finding on fidelity, it is that procedural tasks (rule-based performance) transfer as well as from low fidelity training devices as from high fidelity training devices. However, even low fidelity devices (such as photographic mock-ups) need to be specific to the equipment (control room) of interest to be most likely to produce positive transfer. High fidelity devices seem to produce better transfer of perceptual motor skills to actual equipment than do low fidelity devices, although when transferring perceptual motor skills from low fidelity devices to actual equipment rapid adaptation to the equipment typically occurs. However, if there is no time for adaptation--i.e., first shot transfer is important, not savings transfer--then high fidelity devices are better for training purposes than low fidelity devices. Little research has been carried out on the relationship of fidelity issues and the transfer of knowledge-based performance, but researcher opinion is that high fidelity devices would be best for training such performance. While research is sparse regarding fidelity and team training, the research that exists suggests that team performance does need to be trained and such training is best done in a full task, high fidelity device after individual operator skills have been learned. Finally, an analysis of operator tasks has found that certain types of tasks require a plant-reference simulator for complete learning. Thus, the research literature suggests that high fidelity devices are as good as or better than low fidelity devices in producing positive transfer and that plant-reference simulators are needed to practice skills that are specific to a given NPP.

Since operators and instructors are most directly involved with training device and simulator issues, it is important that their opinions and attitudes be factored into the decision making process. Operators have a strong desire for training on site-specific (i.e., plant-reference) simulators. While they believe that certain training benefits can be derived from training on generic simulators, they believe that this should be followed by training on a site-specific simulator. Instructors also strongly agree that site-specific (i.e., plant-reference) simulators are needed for operator training and evaluation purposes and that their training programs need to include more simulator training.

The panel of experts was also unanimous in its opinion that plant-reference simulators should be required for training purposes in the nuclear utility industry. Some of their reasoning came from cost benefit and legal considerations which deal with utility motivations and not areas of NRC domain. However, the panel also believed that NPP operators wanted to be able to train on plant-reference simulators, and this desire should be given strong consideration in the training device and simulator decision making process. The most important reasons for requiring plant-reference simulators were based on psychological learning principles and simulator research. These include:

- Skill-based behavior is best learned on a plant-reference simulator.
- A motor behavior learning episode should culminate in a precise, appropriate response.
- Rule-based behaviors, which can be learned well on a low fidelity device, still need to be practiced on a plant-reference device.
- Feedback needed for learning to take place is most effective when it is precise; the most precise feedback comes from a high fidelity, plant-reference training device or simulator.
- The maintenance of complex operator skills requires extensive practice, and this can best be achieved if each NPP has its own plant-reference simulator.
- Negative transfer is an ever-present danger on low fidelity and/or generic training devices, so that high fidelity, plant-reference simulators are the best way to preclude negative transfer.

Thus, theoretical analysis of training effectiveness and operator job requirements, the research literature on simulator fidelity and training effectiveness, operator opinion, instructor opinion, and advisory group opinion strongly suggest that plant-reference simulators should be required for operator training/requalification. However, an analysis of the research on part-scope trainers and other training devices suggests that sufficient technical justification does not exist for requiring the use of such devices in operator training/requalification programs.

6. ALTERNATIVES TO THE USE OF PLANT-REFERENCE SIMULATORS

The purpose of this section is to discuss the alternatives to using plant-reference simulators for operator licensing examination and operator training purposes. The benefits or disbenefits of the alternatives compared to the plant-reference simulator are included.

6.1 Alternatives to the Use of Plant-Reference Simulators for Operator Licensing

In Section 4 we recommended that plant-reference simulator examinations be required for the licensing examination process, in addition to written and oral exams. The three possible alternatives to this recommendation are:

- written and oral exams only
- generic simulator exam plus written and oral exams
- operating exam on plant plus written and oral exams.

Before we list specific testing considerations that make a plant-reference simulator exam better than the above-listed alternatives, we need to make the following points. First, there is no research finding that says that you have to use a plant-reference simulator exam to test adequately an operator's ability to handle the plant. However, the research data do show that a site-specific (i.e., plant-reference) simulator exam is the best (most valid) way to test certain types of performance. Therefore, if the concern is to develop the most valid test possible, then a plant-reference simulator exam is needed. Second, the opinion of those involved with the licensing exam and the opinion of test experts is important and should be factored into the decision making process. It is quite clear that the panel of experts believed that a plant-reference simulator exam is needed in the nuclear power plant operator's examination process. It is also clear that licensing examiners and instructors believe that the simulator exam is highly valid and is the most valid way to test certain types of performance. Thus, from the perspective of those involved with the examination process and from the perspective of experts, plant-reference simulator exams should be used.

6.1.1 Written and Oral Exams Only

The major benefit to using only written and oral exams is the examiner time that is saved plus the fact that the plant-reference simulator may not have to be purchased. However, there are numerous reasons why the plant-reference simulator exam, used in conjunction with written and oral exams, is a superior testing technique. These reasons include:

- A simulator exam is a type of work sample exam, and work sample exams have been shown to have more test validity than other exam types for purposes of selecting candidates who have already acquired the job performance requirements.

- If a work sample exam is needed to test, especially, sensory/perceptual, communicative, and motor performance, then a simulator (or the actual plant) has to be used.

- If a work sample exam is needed to test the operator's ability to carry out nearly simultaneous performance requirements in the full-task environment, then a simulator (or the actual plant) has to be used.

6.1.2 Generic Simulator Exam Plus Written and Oral Exams

For this alternative, the only difference is that a generic simulator, rather than a plant-reference simulator, is used for the simulator exam. The major benefit is that many power plants would not have to purchase a plant-reference simulator. The main disadvantages include:

- While a generic simulator exam is a work sample test, a plant-reference simulator exam is a better work sample test than is a generic simulator exam.

- Negative transfer of training, either from the plant to the generic simulator or from the generic simulator to the plant, cannot be precluded.

- In addition, administering licensing exams on a generic simulator has already been tried and dropped by the NRC because of test administration concerns.

6.1.3 Operating Exam on the Plant Plus Written and Oral Exams

The major benefit of carrying out an exam on the plant is that no simulator need be purchased. However, the drawbacks preclude using such a test:

- Taking a plant off line to conduct such tests is very expensive.

- Even though such an exam would be of a work sample exam type, the work sample would have to be severely limited, i.e., not include any emergency events and few abnormal events.

- Carrying out even a normal operations work sample exam on the plant could damage the plant or cause unanticipated down time.

6.2 Alternatives to the Use of Plant-Reference Simulators for Operator Training

In Section 5 we discussed the need for plant-reference simulators for operator training. Possible alternatives to this are:

- continuation of present-day practice of using generic simulator training

- use of plant-reference part-scope training devices

- training through maneuvering the plant.

Before listing the advantages and disadvantages of these alternatives, the opinions of experts, instructors, and operators need to be briefly summarized. In short, operators and instructors strongly favor the use of site-specific (i.e., plant-reference) simulators for training and evaluation purposes. The panel of experts also strongly agreed on the need for plant-reference simulators for operator training/requalification purposes.

6.2.1 Continuation of Present-Day Training Practice

Present practice is to require approximately 2 to 4 weeks per year of generic simulator training for license candidates and approximately 1 week per year for requalification candidates. The benefit of staying with this practice, as compared to requiring plant-reference simulator training, is that present training schedules could be maintained and a plant-reference simulator need not be built. The disadvantages of training on the generic, as opposed to a plant-reference, simulator include:

- The training of certain types of operator performance cannot be done on a generic simulator and therefore requires a plant-reference simulator.

- The possibility always exists that there will be negative transfer of training from a generic simulator to the plant while such is not the case on a properly built and maintained plant-reference simulator.

- Generic simulators are in high demand, which consequently limits the amount of time that any given operator can practice on it, whereas a plant-reference simulator would allow individual operators much more practice time.

6.2.2 Use of Plant-Reference Part-Scope Training Devices

One possible alternative to using a plant-reference simulator would be to use plant-reference part-scope training devices and principles trainers. While these devices would not have the disadvantage of negative transfer present with a generic simulator, compared to using a plant-reference simulator training only with these devices is still not as good because it:

- does not allow for team training

- does not allow subtasks or tasks learned on part-scope devices to be integrated with other subtasks or tasks and then practiced in the full-task environment.

6.2.3 Training Through Maneuvering the Plant

Training on the actual plant is a possibility and would not require the purchase of simulators or training devices. However, problems such as the following are too great to overcome:

- Taking the plant off line can be very expensive.
- No emergency operations and few abnormal operations could actually be practiced.
- Maneuvering the plant even through acceptable scenarios could cause damage to the plant and unanticipated down time.

PART II. THE USE OF PLANT-REFERENCE SIMULATORS

1. PURPOSE AND OBJECTIVE

The purpose of Part II of this report is to discuss concerns associated with the effective incorporation of plant-reference simulators into operator licensing and training programs. Should a regulatory requirement for plant-reference simulators be put forth by the NRC, it is important that initial direction be given by the NRC to the nuclear power industry with respect to the implementation of the use of simulators in operator licensing and training.

To this end, the objective of Part II is to provide information to the NRC on the use of simulators in NPP operator licensing and on the use of simulators and training devices in operator training programs. The discussion of the use of simulators for testing operators addresses:

- reliability and validity as central concepts in test theory
- maximizing reliability and validity in simulator examinations of nuclear power plant operators
- opinions of licensing examiners and operators concerning the licensing examination.

The discussion of the use of simulators and training devices in NPP operator training programs addresses:

- the systems approach to integrating plant-reference simulators into nuclear power plant training programs
- the structuring of simulator training based on proven learning principles
- the selection and training of simulator instructors and the selection of instructional support features for simulators
- the evaluation of the effectiveness of the training program
- maintaining the effectiveness of the training program.

2. THE USE OF PLANT-REFERENCE SIMULATORS IN OPERATOR LICENSING

The operator licensing examination, as required by the NRC, is intended to serve as a method for determining which individuals have the ability to perform competently as nuclear power plant operators. This testing process actually involves three examinations: written, oral, and simulator. Consistent with the focus of this report, the purpose of this section is to discuss recommendations for the use of plant-reference simulators as a method for testing nuclear power plant operators for licensing purposes. However, these recommendations are also generally applicable to the training staff evaluation of license candidates and licensed operators.

Any recommendations regarding the use of plant-reference simulators for testing operators should be based on sound principles of employee testing. These principles are discussed below and are an integral part of our recommendations.

2.1 Central Concepts in Testing--Reliability and Validity

Two very important concepts of employee testing are reliability and validity (Guion, 1965). Reliability refers to consistency (e.g., do two examiners evaluate a candidate the same?). Validity is concerned with whether the test measures what it is supposed to measure (e.g., does it accurately assess whether a candidate will perform competently on the job?).

Both reliability and validity must be maximized to ensure that qualified candidates are selected and unqualified candidates are not selected. Reliability is important because it sets limits on validity. That is, if a test is unreliable it is unlikely that it can be measuring what it is supposed to measure--job performance. An analogy to this is a scale for measuring weight. If it is unreliable (i.e., every time you weigh yourself you get a different weight), it is unlikely to be valid, i.e., measuring what it is supposed to measure--your actual weight.

Thus one major consideration for employee testing is whether the test is reliable. The second, more important consideration, however, is whether the test is valid, i.e., whether the test measures what it purports to measure. It is possible that a testing procedure is perfectly reliable but not valid. For example, suppose we tried to assess operator performance by determining the weight of the operators. We assume we could determine weight reliably; however, even a casual observer would have grave doubts as to whether this (reliable) measure accurately assesses operator performance. Validity is of primary importance for employee testing because the purpose of the test is to measure a person's ability to perform the job.

To be valid, a test should reflect the abilities required to perform the job. Whether this type of validity exists can be determined in various ways. One of the most common, and the "stepping stone" of other validation methods, is content validity. This refers to whether the test content is representative of the required skills, knowledges, etc. for the job. Content validity is especially appropriate for employee tests that require a determination of whether a candidate has mastered certain skills. Both licensing examiners and operators have indicated that the simulator exam can measure a person's abilities in a control room situation, especially for emergency events (Saari et al., 1983). However, from the standpoint of content validity, it is important that the abilities tested for in the simulator exam in fact reflect those required on the job. Obviously, to ensure that a test has content validity, the content area (i.e., the job skills, knowledges, etc.) need to be described fully in advance. Content validity should be built into a test from the outset (Anastasi, 1982). This requires a thorough job analysis to determine the specific requirements of the job.

2.2 Maximizing Reliability and Validity in Simulator Examinations

As the above discussion points out, it is important to design a test in such a way that it will be both reliable and valid. The following five recommendations for the use of simulator exams in operator licensing reflect the goal of maximizing both reliability and validity. It should be noted that the recommendations specify what should be done, but the details of how (e.g., on what specific scenarios should candidates be tested?) are meant to be determined by the NRC, working in conjunction with the utilities.

2.2.1 Use of a Core Set of Standardized Scenarios

The first recommendation is that a core set of standardized scenarios, which reflect important operator job skills required in all plants, be used for the simulator exams for all license candidates, if possible. The term, standardized scenarios, means that there is consistency in the types of scenarios each examiner uses during the simulator exam. For example, examiners could use certain types of emergency events. By requiring that a core set of standardized scenarios be used for all simulator examinations, reliability is increased. By having the scenarios reflect what is required on the job, content validity is enhanced.

To maximize content validity, the core set of standardized scenarios should be based on the results of a job analysis of the nuclear power plant operator. The current Institute of Nuclear Power Operations (INPO) job task analysis appears to be well suited for developing a core set of standardized scenarios. The INPO has completed a job task analysis of PWR plants and is scheduled to have a BWR job task analysis available by 1984. Based on the INPO job task analyses (or any other comprehensive job analyses that may be available), potential scenarios could be developed for use in all simulator exams. However, to ensure that emergency scenarios reflect not only what is designated in the job analyses (which may reflect only the more common emergency events), other strategies for incorporating important emergencies scenarios might be considered. For example, probabilistic risk assessments could be examined when developing a core set of scenarios. This could help ensure that operators are tested on important but infrequent incidents.

The purpose of having a core set of scenarios is to help ensure comparability across plants and NRC regions. Again, this pertains to issues of reliability and, to the degree the scenarios reflect the job, content validity. However, to maximize fully the content validity of simulator exams, each examination would probably need to go beyond the core set of scenarios to include scenarios that are specific to a given plant. This issue is discussed as part of the next recommendation.

2.2.2 Use of Plant-Specific Scenarios

The second recommendation for simulator exams is that candidates should be tested on not only a core set of scenarios but also (if necessary) on scenarios that reflect unique performance requirements at their particular plant. Because the goal of ensuring validity is to measure what is actually required of operators on their jobs, any unique aspects of a plant that require certain skills of operators should be tested for as part of the simulator exam. The necessity for, and extent of, uniqueness in scenarios would be determined by reviewing what is required of operators at each plant. This could be done by examining the results of a job analysis developed for a specific plant. Other methods for determining scenarios that are content valid for a particular plant are to examine training materials, technical specifications, or, more importantly, the prior operating experience at that or a similar plant (e.g., as reported in Licensee Event Reports). This operating experience could help ensure that operators are tested on emergencies that have been determined to be important for their specific plant. Also, the results of probabilistic risk assessments done for the specific plant can be used as a source for specific scenarios.

The more unique the scenarios are for a specific plant, the more likely certain types of reliability may be threatened. This is because there will be less standardization and thus, less comparability of simulator exams for different plants/regions. Nonetheless, other indices of reliability can still be estimated (e.g., inter-rater reliability and test-retest reliability) that may be more appropriate within the particular context of the NRC licensing exam. Moreover, to the degree that the uniqueness of the exam reflects actual unique aspects of the operator's job at a plant, content validity is enhanced.

2.2.3 Use of Standardized Procedures for Administering Examinations

The third recommendation is that standardized procedures for administering simulator exams should be used (e.g., the number and order of scenarios, the length of the exam, the positions of others taking part in the exam, whether the simulator is frozen for discussion with a candidate). Standardization of test administration is extremely important for assuring reliability (Guion, 1965). Practical constraints (e.g., amount of simulator time available, whether other candidates are being tested at the same time or if "role-players" must be used to create a full crew) may preclude having exactly the same administration procedures of simulator exams for all candidates. However, to the degree that simulator exams can be administered as consistently as possible, the likelihood of reliability is increased.

2.2.4 Use of a Standardized Method for Grading

The fourth recommendation is that a standardized method for grading candidates on simulator exams should be used. If a standardized grading form is used consistently by all examiners, reliability (e.g., comparability across examiners/plants/regions) can be maximized. Validity also can be enhanced if the grading form reflects the performance required of operators on the jobs.

In order to standardize the grading form for simulator exams, general areas on which operators should be evaluated could be determined (e.g., uses procedures properly, takes correct action at the control board, coordinates activities with other operators, correctly carries out supervisor's directives). These evaluation areas could be used for both core and unique (plant-specific) scenarios. Within each of the evaluation areas, specific activities to be evaluated may vary, depending on the scenario being tested. Again, with regard to content validity, the specific activities on which an operator would be evaluated should reflect what is required on the job.

Optimally, the grading form should have clearly defined rating scales for each activity being evaluated. Various approaches can be used to develop rating scales for evaluation purposes. These are described in the organizational-psychology literature (e.g., Fleenor and Scontrino, 1982; Latham and Wexley, 1981).

The use of a standardized grading form also helps minimize a problem that is present whenever human judgment is involved, called rater errors. Rater errors are errors in judgment that people make unknowingly when evaluating others. Examples include rating a candidate higher on all scenarios because of effective performance on one scenario and rating a person higher because of similarities in background, interests, and other factors. Again, standardized grading forms help minimize the negative effects of rater errors, which, if present, can adversely affect reliability.

Another method that can be used to standardize the grading is to use some type of machine scoring. For example, General Physics is currently developing a Performance Measurement System that can be used to evaluate operator responses. Using such a system would raise the objectivity of the scoring process and thus the reliability. However, such a system also needs to be very flexible, since in many NPP abnormal and emergency situations there are several ways to mitigate a given symptom. At present, objective performance measurement systems in the nuclear industry are in their infancy. If flexible systems can be developed, their use would go a long way toward helping standardize the simulator examination.

2.2.5 Examiner Training in Test Examination and Grading

The final recommendation for the use of plant-reference simulators in operator licensing is to train examiners on the administration of the simulator exam and the use of the grading forms or performance measurement system. Reliability can be assured only to the extent that the standardized methods developed are in fact applied in a consistent way. Thus, examiner training is important for maximizing the effectiveness of the simulator exam in the operator licensing process.

2.3 Recommendations from Examiners and Operators

The recommendations discussed above are based on sound principles of testing that have been applied extensively in industrial, business, and educational settings. It should be pointed out, however, that these recommendations also reflect ideas/concerns expressed by two user groups of the licensing exam: examiners and operators. Input was obtained via a survey of examiners and from operator workshops (Saari et al., 1983). Comments from these two groups on the simulator exam included:

- guidelines for simulator exam topics (scenarios) are needed
- grading is difficult
- pass/fail criteria should be determined
- subjectivity of evaluations is a problem
- examiners should have plant-specific experience (can help ensure content validity).

Note that these concerns basically deal with test reliability and validity issues. Thus, if the five recommendations are implemented, these concerns are likely to be alleviated.

2.4 Summary

In summary, the recommendations proposed in this report for the use of plant-reference simulators in operator licensing are as follows:

- Use a core set of standardized scenarios that reflect important operator job skills that are needed in all plants.
- If necessary, also administer unique scenarios that reflect particular job skills required at a specific plant.
- Use a standardized procedure for administering simulator exams.

- Use a standardized grading form or an objective measurement device, if available, for evaluating candidates on simulator exams.

- Train examiners on the administration of the simulator exam and the use of the grading form or objective measurement device.

3. THE USE OF PLANT-REFERENCE SIMULATORS IN OPERATOR TRAINING PROGRAMS

The purpose of this section is to provide information on the use of plant-reference simulators in operator training and requalification programs. Information will be provided in several areas, including the use of a systems approach to training, simulator procurement, structuring simulator training, the simulator instructor and instructor station, the assessment of training effectiveness, the maintenance of positive attitudes toward simulator use, and maintaining the simulator training program. The authors acknowledge their debt to the work of Dr. Paul Caro and his colleagues at Seville Research Corporation on simulator utilization. Much of the following section is based upon one of their recent publications, the purpose of which was to analyze the use of simulators in the U.S. Air Force and to provide guidance on ways to enhance the effectiveness of simulator training and efficiency of use of the devices (Caro, Shelnutt and Spears, 1980).

3.1 The Systems Approach to Training

The effective use of a simulator is dependent upon the full training program within which it is employed. While a plant-reference simulator probably has the ability to enhance training effectiveness even through mediocre training use, its full potential as a training aid can be realized only within a well-organized training program. The first step in developing such a program is to apply some sort of systems approach to training (SAT).

The purpose of this section is to outline briefly the SAT and one specific type of SAT used extensively in the U.S. military, the Instructional Systems Development (ISD) process (Vineberg and Joyner, 1980). Drawbacks of the ISD are also presented.

The SAT is not a specific training approach. It is a general approach that, according to Stammers and Patrick (1975, pp. 17-18):

> . . . basically looks at the different functions of the components of any process and examines their interrelations not only with each other but with other processes . . . . As such this approach can view any functioning entity as a system, the important thing being to define its objectives. In other words, a system is defined in terms of what it is attempting to achieve.

Stammers and Patrick (1975) present several training models. A simple SAT model, borrowed from Eckstrand (1964), included:

- defining training objectives
- developing criterion measures
- deriving training content

- designing training methods and training materials
- carrying out the training program
- evaluating the training process
- providing feedback to the above processes so as to refine the overall training program.

The ISD process is also a specific form of the systems approach to training. As discussed by Jones (1979), the U.S. Air Force and a multiservice committee of the U.S. Department of Defense have prepared guidebooks to proceduralize the ISD process. The ISD model as presented in Air Force Manual 50-2 (1979) employs five general steps:

- Analyze system requirements through a job task analysis.
- Define the training requirements based on the job task analysis.
- Develop instructional objectives and tests for evaluating whether the objectives were met.
- Plan, develop, and validate the instructional package, including the determination of the need for simulators.
- Conduct and evaluate the instruction.

Continual feedback between the steps of the model is considered crucial.

The actual ISD process employs 19 steps. These steps, and the deficiencies associated with their implementation, are discussed by Vineberg and Joyner (1980). However, rather than discuss specific deficiencies like these, general problems with the SAT/ISD approach will be presented.

One problem with the SAT/ISD approach is that it is usually applied too late to be of use for simulator procurement purposes (Jones, 1979; Caro et al., 1980). This could easily be a problem, also, in the nuclear industry. Timing decisions will have to be made regarding whether plant-reference simulators should be ordered before some sort of SAT is developed or not.

A second problem (Jones, 1979) is that the SAT/ISD analyses are often carried out in isolation to actual performance data and/or engineering data. Third, the analyses tend to emphasize procedures and normal operations with little to no emphasis on emergency operations. This is probably because normal operations are easier to specify, but it is clear that the nuclear utility industry will need to analyze carefully tasks that operators need to carry out during abnormal events and emergency events. Fourth, the SAT/ISD approaches are not good at specifying psychomotor skills; however, this is likely more of a problem with aircrew skills than reactor operator skills. Fifth, there is typically no way to determine whether a task has been specified correctly unless it can be verified on an engineering simulator or on actual equipment.

A sixth problem (Jones, 1979; Christensen, 1982) is that the SAT/ISD process is not good at specifying complex, cognitive tasks (i.e., knowledge-based behavior). This problem must be overcome in the nuclear utility industry to specify the knowledge and decision-making skills needed during emergency events.

A final problem, discussed by Jones (1979) and Caro et al. (1980), deals with the assumption that once an analytical training process has been developed in "cookbook" form, anyone can apply the process and set up an efficient and effective training program. This is simply not true. In developing something as important as a simulator training program, utility instructors might benefit greatly from professional training help.

In summary, some systems approach to training should be adopted by the nuclear utilities so that decisions regarding plant-reference simulator use are made in a logical fashion. However, various systems approaches have not been without their difficulties in terms of application in the military. These difficulties, especially with regard to specification of complex tasks, must be overcome in the nuclear application. Professional training assistance may be needed. Also, although employing some form of SAT is the optimal method for developing a training program, the development of a training program should not be delayed unduly by the SAT process or by waiting to carry out some aspect of it, e.g., the task analysis. For example, training programs that are already in place should continue; insights gained through application of the SAT can be incorporated into the ongoing program.

3.2 Simulator Procurement and Introduction

Caro et al. (1980) listed six areas of guidance regarding the procurement and introduction of a simulator into a training program:

- Instructors and operators, who will be the eventual users of the simulator, should be actively involved in the design of the device.

- Instructors and operators should be actively involved in the simulator acceptance testing.

- To guard against ineffective simulators or simulator training programs, instructors should be encouraged to become advocates for simulator training, and should be selected, trained, and managed with this in mind.

- To assure a smooth transition to simulator training, the planning for the introduction of the simulator into the training program should begin early in the simulator procurement process.

- Changes in training that might disrupt established training procedures should be introduced before the simulator is introduced to avoid their affecting the users' initial impressions of the simulator

- All elements of the training program should be functioning smoothly before the simulator is introduced for training, to avoid confounding new problems with old.

If this guidance is implemented, it can foster strong positive attitudes toward the use of a simulator for training. In addition, the transition to a training program that includes a simulator will go smoothly and not negatively affect trainer and operator acceptance.

3.3 Simulator Training

To carry out effective simulator training, the training should be structured and conducted according to proven learning principles involving task sequencing, duration and frequency of practice, cognitive learning, feedback, and guidance. Scheduling and provisions for what to do if the simulator is unavailable also need to be considered. Guidance on these issues is presented below.

3.3.1 Structuring Simulator Training

Caro et al. (1980) list four considerations relevant to structuring plant-reference simulator training for NPP operators:

- priorities for simulator scheduling

- sequencing simulator training with other types of training

- organizing tasks for practice

- duration and frequency of practice.

Consideration also should be given to introducing licensing examiners to the plant-specific features of the simulator.

Simulator scheduling is necessary because of the myriad of uses for a plant-reference simulator. Two types of priorities need to be determined:

- priorities on the different types of training and uses of the simulator (e.g., operator candidate training, requalification training, management familiarization, licensing examinations, examiner training, and public tours)

- priorities on the different types of training needs within a given training group (e.g., for license candidates priorities should be developed for training for normal, abnormal, and emergency conditions).

Once the above priorities have been set, a schedule for the use of the plant-reference simulator can be determined. However, the scheduling should also make provisions for simulator unavailability due, say, to maintenance problems.

Sequencing of simulator training with other types of training is also important. Decisions need to be made regarding whether initial familiarization for a given concept or system for an operator should occur in the classroom, in the simulator, or in the control room. Much of the time classroom instruction should provide the initial familiarization, which should then be followed by simulator training. The less experience a trainee has, the more quickly simulator training should follow classroom instruction. Sometimes initial familiarization has to come on the simulator or even the actual control room to make classroom instruction meaningful. Decisions also need to be made about interspersing simulator practice with actual control room practice when feasible.

Tasks need to be organized in a meaningful way in the simulator practice sessions. Two general learning principles discussed by Caro et al. (1980) are:

- Stimulus and response complexity should be low during early stages of learning any task.

- Performance of related subtasks should eventually be practiced in the full-task situation.

The best way to learn many complex tasks is to break the tasks into subtasks and learn them separately. This can reduce inter-subtask interference and will allow the trainee to see more easily that learning is occurring.

Three "rules of thumb" are provided for making decisions about dividing complex tasks into subtasks:

- Tasks that require small amounts of practice to master should be separated from tasks requiring large amounts of practice to master.

- Tasks that can be mastered by repeated practice, which pertains especially to perceptual motor tasks, should be practiced separately from other tasks.

- Natural "break points" should be found within a complex task and used for subtask separation decisions.

Whatever task grouping that is decided upon has to make good sense to the instructors and the trainees. Finally, once the subtasks have been learned, they need to be integrated and practiced in a whole task fashion.

An often-asked question in simulator training is how long and how often should a task be practiced. Caro et al. (1980) list three variables that must be considered in making those decisions:

- the effects of interference
- level of previous learning
- amount of forgetting during training.

Interference between two tasks, subtasks, etc. should be avoided both to make learning faster and to keep wrong responses from being learned which then need to be unlearned. Intertask interference can be minimized in several ways:

- Use training breaks.
- Separate the practice of the tasks if the two tasks are likely to produce intertask interference.
- Ensure that trainees learn completely the first task or subtask before moving to the second.
- Keep practice sessions of a length such that boredom and fatigue are not induced.

The level of previous mastery (learning) has been shown to be the largest single determinant of what is remembered (Prophet, 1976; Schendel et al., 1978). Tasks that require correct performance the first time that they are experienced should be overlearned, i.e., practiced well beyond the first time that the task is performed correctly. Thus, as stated by Caro et al. (1980, p. 76):

> A rule of thumb in deciding how much practice should occur for [aircrew] mission tasks is to continue practice until, as past experience has shown, correct performance can be assured the next time that task is performed.

How would this apply, for example, to mitigating emergency events? Because such an event could occur at any time during most modes of reactor operation, an operator should always have the ability to mitigate such an event. Thus, if an operator is provided with such an event on the simulator and handles it incorrectly, this indicates that more practice is needed on such events. Practice should occur on such events until the operator has the ability to handle the event the next time it is required, whether this is during an unexpected simulator evaluation, during a planned simulator evaluation, or when a real event occurs.

The amount of forgetting is closely related to the above concept. The suggestion here is that practice occur frequently enough so that forgetting is prevented for tasks that must be performed correctly the first time that they are encountered and frequently enough so that a serious impact on performance is prevented for tasks that allow some latitude for error when they are encountered.

The discussion on interference, level of previous mastery, and amount of forgetting led Caro et al. (1980) to three criteria for scheduling simulator practice on a given task.

- The time between practice sessions should not be so long as to allow noticeable decrements in performance to occur.

- Frequent but short duration practice sessions would be best for license candidates, especially early in their training.

- Interference effects are greatest for yet unmastered tasks.

- For highly experienced operators and senior reactor operators, concentrated practice within relatively long simulator training sessions is probably more efficient than distributed short practice sessions, especially because such operators have probably experienced less forgetting than less experienced operators and because the tasks have been learned well enough to preclude many of the interference problems.

3.3.2 Conducting Simulator Training

Caro et al. (1980) discussed three factors that need to be considered by the trainers while conducting simulator training:

- teaching knowledge-based performance (i.e., cognitive training)

- informing the trainee about the appropriateness of his actions (i.e., feedback or knowledge of results)

- guiding the trainee during task acquisition (i.e., guidance).

These three factors, and their relationship to simulator training, are discussed below. These factors are not unique to training on a simulator. They are good instructional practice in any training situation. However, it is important to remember that even very sophisticated simulators do not train operators. Effective learning comes from a systematic structuring of the interaction between the trainee and whatever training medium is being used.

The major point to be made about cognitive training is that a trainee must be told what to think about and how to make decisions during training. As discussed by Marshall and Shepherd (1977) in their study of systematic fault-finding strategies in the operation of a petrochemical plant simulator (p. 59):

> While only a small proportion of trainees may be capable of generating really effective diagnostic principles for themselves, it is likely that a much higher proportion of them

would be capable of <u>using</u> such principles if they were taught them. (Their emphasis.)

Thus, a major training task is to make sure that knowledge-based performance (cognitive skills) is acquired by the trainees as they are practicing tasks on the simulator. The instructors should tell the trainees how to conceptualize a given situation and encourage the students to practice these cognitive skills as they practice the task. In addition, briefings before or after a practice session should be used to keep the trainees from learning incorrect decision-making skills and from learning to make responses based on stimuli that are peculiar to the simulator but not the plant.

For a trainee to learn, he must be presented feedback regarding the adequacy of performance. Feedback also serves a motivational purpose. There are two types of feedback--intrinsic and supplemental. Intrinsic feedback is that feedback which occurs naturally during the performance of a task (e.g., when you manipulate the control for a flow control valve, the change in flow rate as indicated on a display is intrinsic feedback). During early simulator training on a task, the instructor should point out what constitutes relevant intrinsic feedback. If the intrinsic feedback occurs, say, too quickly for the trainee to use it easily, the feedback can be augmented, i.e., changed in such a way that the stimuli can be easily discriminated by the student. For example, replaying a task in slow time or using repetitive replay of the same task in a short period of time are ways of providing augmented feedback. Thus, instructors need to determine when augmented feedback is necessary for efficient training to take place.

In some cases supplemental feedback may be needed for a task to be learned efficiently. Supplemental feedback is feedback that is not intrinsic to the task but is provided for learning to occur. Determinations should be made as to when supplemental feedback may be needed. However, it is important that supplemental feedback be withdrawn as the task is learned so that correct task performance, in the end, is based only upon intrinsic feedback.

Typically, any type of feedback is best when it is delivered as soon as possible after the response. However, feedback is useful to a trainee so long as the trainee can remember the stimulus and response conditions to which the feedback pertains. Thus, debriefing sessions as a form of supplemental feedback are very useful if the task is still "fresh" in the trainee's mind.

Guidance deals with an instructor's directing the trainee's actions toward successful task completion. Note that guidance occurs before an action is taken while feedback occurs after the action. Caro et al. (1980) state that guidance helps to speed task mastery in two ways:

- when it is used to point out the relevant stimuli and responses

- when, by pointing out relevant stimuli and responses, a trainee is less likely to learn incorrect cognitive strategies or motor responses that would then have to be unlearned.

It follows from this that guidance is especially helpful during early learning on a task or in re-establishing skills that have been allowed to deteriorate seriously. Guidance can be offered verbally by the instructor or it can be provided by the simulator, e.g., by using automatic demonstrations. Guidance can be overdone, however, so that the student becomes dependent upon the guidance to carry out the task. Thus, a simple rule of thumb regarding guidance is to withhold guidance to see if learning progresses without it. If it does, then the guidance is no longer needed.

3.4 The Simulator Instructor

The simulator instructor or trainer is very important to the success of any simulator training program. This section will discuss the need to select and train simulator instructors and the types of instructor station attributes that should be considered.

Not just anybody can be a good instructor or, more specifically, a good simulator instructor. Therefore, simulator instructors must be selected on the basis of characteristics such as maturity and stability, teaching ability, and knowledge of plant characteristics. Although a simulator instructor does not have to be or have been a licensed operator, such a background can make the instructor more credible and thus more acceptable to the trainees.

Given that valid selection criteria do not exist for good simulator instructors, the need to train whoever is selected is elevated in importance. It is a commonly-accepted truism in the field of training that training any instructor, including a simulator instructor, is an often overlooked but enormously important consideration. The instructor should be trained as an instructor, intimately familiar with the plant, and intimately familiar with the simulator instructional capabilities. In addition, the simulator instructor should receive continuation training. This not only keeps the instructor up to date on new instructional techniques and the use of existing simulator instructional capabilities, but it also maintains strong positive attitudes in the instructor toward the use of the simulators for training.

The instructor station on the simulator is an important aspect of the instructor's role in training and the effectiveness of the overall training program. Keegan (1977) has listed three basic objectives of the instructor's station (p. 12):

> To minimise the attention which the instructor has to give to the machine [simulator], thereby maximising the time which he has available to teach and to monitor the actions of his trainee.

To maximise the instructor's ability to control the simulation, and extract the greatest benefit from the inherent flexibility and built-in training aids.

To exploit the power of computers to aid in the instructional task by data logging, student output monitoring, and relieving the instructor of routine data logging chores.

Cream et al. (1978) make more explicit the fact that the instructor's station should support the measurement of trainee performance, the display and recording of the performance in a useful format, and the presentation of this information to the trainee as a form of feedback.

In terms of specific instructional capabilities, Montemerlo (1977) has listed the following training features that should be available on the simulator, which would be controlled from the instructor's station: malfunction insertions, automated briefings, automated demonstrations, performance recording and playback, parameter recording, automated performance measurement, out-of-tolerance alerts, remedial messages, adaptive training, guided practice, and augmented feedback.

NUREG/CR-1482 assessed the training features of existing simulators against generic considerations and the criteria set forth as recommended standards in the 1979 edition of ANSI/ANS-3.5. Their analysis indicated that the typical training features being incorporated (which included all of the features listed in ANSI/ANS-3.5) were malfunction insertion, real time, fast time (ten times real time), slow time (one-tenth of real time), freeze, snapshot, backtrack, recall, replay, cry wolf (i.e., the ability to provide false indications), condition override (i.e., ability for instructor to intercept the signal from the computer to the simulator and to change it), and trainee performance and feedback.

All of these instructional capabilities may or may not be needed on a plant-reference simulator. In the interests of enhancing the degree to which the instructional features of simulators correspond to specific training needs, Caro et al. (1979) have proposed a process that can be used to make such decisions. In this process, to arrive at the instructional features for a specific simulator, Caro et al., recommend analyzing:

- the instructional features of existing simulators and the manner in which they are used during training

- the performance specifications of other simulators under development

- discussions with, for example, NPP licensed operators and instructors with respect to their training practices, experiences, and adaptations of equipment

- the roles of the principal personnel to be involved in the instructional process for the type of simulator under consideration (e.g., the roles of the instructor, the operator trainee, and the device technician)

- typical characteristics of the learners who will be trained on that simulator.

From this analysis, relevant instructional features can be specified and a design guide prepared. The guides provided by Caro et al. (1979) typically define each particular instructional feature, state its purpose and intended use, and describe its function as well as concurrent events. Such a guide can, among other things, become the mechanism for communicating to the designer the simulator design capabilities required by training personnel.

3.5 Assessment of Simulator Training Effectiveness

As discussed in Section 3.1, every training program model states that the whole training program, including the simulator training portion, needs to be evaluated. Unfortunately transfer of training research is complex, time-consuming, and often expensive to conduct. Nevertheless, some sort of effectiveness evaluation is needed. Caro et al. (1980) offer the following guidance regarding training effectiveness studies.

- Consideration should be given to obtaining professional assistance to define the research paradigm, the performance measurement needs, the statistical analyses, etc., before conducting such an evaluation.

- The evaluation should consider the objectives of simulator training and the way the simulator is actually being used.

- The evaluation should be conducted so that it could be repeated by a different evaluator.

- The evaluation should give preference to transfer designs.

- The measures of trainee performance ought to be valid, reliable, and capable of being objectively measured.

- The performance data should be collected under standardized conditions and by persons who are independent from the simulator training program.

- The evaluation report should be written so that a different evaluator could read the report and make judgments as to the possible reliability and validity of the evaluation results.

3.6 Maintaining Positive Attitudes Toward Simulator Training

When a plant-reference simulator is first installed, no doubt most of the management, instructors, and operators will have strong positive attitudes toward the use of the simulator and toward the validity of training that the operators are receiving. However, these positive attitudes may begin to lose strength if they are not nurtured.

The simulator instructors are probably the most important key to maintaining strong positive attitudes. Thus, for instructors to maintain these attitudes they should have a continued voice in changes in the training program or simulator, they should receive continuation training, and they should be encouraged to aspire to high levels of professionalism.

The instructors can then serve as effective role models for the operators and thereby maintain positive attitudes in the operators. Finally, management must remain firmly convinced of the need for and usefulness of simulator training. Otherwise, their negative attitudes can affect the instructors and operators. Also, training effectiveness studies, when results are positive, can go a long way in developing positive attitudes among the managers.

3.7 Maintaining the Simulator Training Program

The final guidance on simulator training deals with maintaining the effectiveness of the simulator training program. Some problems are transitory, such as the need to hire and train a new simulator instructor; others persist, however, and can adversely affect training. Caro et al. (1980) list four problems that need careful attention:

- changes in training requirements
- modifications to the NPP
- inadequate maintenance support for the simulator
- deterioration of the simulator training program itself.

Changes in simulator training requirements can come from several different sources, including new NRC guidance, the addition of other training devices to the training program, and feedback from the training effectiveness studies. The points to be made are that these changes should be made as quickly as possible so that the training is not perceived as unnecessary by the operators and that these changes should be made within the systems approach to training.

When the NPP is modified so that the control room is affected, the simulator should be upgraded to meet the modifications. Such is also the case when new operating data become available that question the functional fidelity of some aspect of the simulation.

Inadequate simulator maintenance may mean that simulator availability is a problem. This should not be allowed to happen. An adequate maintenance program should be set up and carried out during off-use hours so that the simulator is available as much as possible. Then the training program will not be disrupted, and negative attitudes toward the worth of the simulator will not begin to be formed.

Finally, the simulator training program itself may begin to deteriorate. Caro et al. (1980) list five general requirements for an effective quality control system for the training program. These requirements are:

- a detailed statement of training objectives based on job requirements
- an accurate and valid performance measurement system
- effective feedback to the operators regarding their performance in training and on the job
- an effective means to take corrective action
- strong supervisory support.

3.8 Summary

The purpose of this section was to provide guidance on ways to enhance the effectiveness of simulator training and efficiency of use of the simulator. Issues were discussed involving:

- use of a systems approach to training
- device procurement and introduction
- structuring and conducting simulator training
- the simulator instructor and instructor station
- the assessment of training effectiveness
- the maintenance of positive attitudes toward simulator use
- the maintenance of the simulator training program.

The point made with regard to the systems approach to training was that the nuclear utilities should adopt some such approach to develop an overall training program and the simulator program within it. However, such approaches have shown drawbacks in their use, especially with regard to being accomplished too late to influence simulator procurement and to specifying operator tasks during emergency events. These problems will have to be overcome in the nuclear utility industry.

Simulator procurement and introduction would benefit from the following guidance:

- Instructors and operators should be part of the procurement process and acceptance testing process.

- Instructors should be encouraged to become advocates for the use of a simulator as a training tool.

- The planning for the introduction of the simulator into the training program should begin early in the simulator procurement process, and should be given strong management support.

- Changes in training that might disrupt the training process should be introduced before the simulator is introduced.

- All elements of the training program should be functioning smoothly before the simulator is introduced for training to avoid confounding new problems with old.

Four considerations are relevant to structuring simulator training:

- Priorities for training on the simulator need to be established, regarding both the groups to be trained and the type of training within each group.

- Decisions regarding sequencing of training--e.g., whether classroom instruction should come before simulator training on a given task or vice versa--need to be made.

- The way in which tasks are broken into subtasks and learned also needs to be structured.

- Decisions regarding the duration and frequency of practice need to be made so as to overcome interference problems, level of previous mastery differences among trainees, and forgetting.

With regard to conducting training, decisions need to be made about teaching knowledge-based performance (especially decision making), providing feedback, and providing guidance. It is important to realize that decision making skills need to be taught. Simulator instructors should be providing this instruction throughout simulator training. Feedback is needed for learning to occur. Decisions need to be made regarding intrinsic and supplemental feedback. Performance measurement systems can be very useful in providing some of this feedback. Simulator instructors also need to provide guidance to trainees to speed learning and to keep inappropriate responses from being learned, which would then have to be unlearned.

The simulator instructor or trainer is the most important person regarding simulator training effectiveness. Instructors should be selected on the basis of skills found useful for simulator training. They also need to be trained on simulator instruction techniques to optimize use of the simulator, and they should be engaged in continuation training. The instructor station is a very important training interface. Several instructional capabilities have been suggested for incorporation into the station. Decisions regarding which instructional capabilities should be incorporated need to be made during the development of the training program.

The assessment of simulator training effectiveness needs to be carried out and professional help is probably needed so that the evaluation is performed using reliable and valid evaluation techniques.

Positive attitudes toward simulator training need to be continually maintained so that the training program is as effective as possible. The simulator instructor is the key to this. The simulator training program must also be flexible so that it can respond to new training requirements, additional training devices, and changes in the plant or the control room that affect the simulator and/or simulator training.

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APPENDIX A

PANEL OF EXPERTS
AND OTHER PANEL
MEETING PARTICIPANTS

LIST OF MEETING PARTICIPANTS
January 20-21, 1983

Expert Panel Participants

David R. Baum, Ph.D.	Honeywell
Paul W. Caro, Ph.D.	Seville Research Corporation
Capt. J. Edward Carroll	United Airlines (Retired)
Julien M. Christensen, Ph.D.	General Physics Corporation
H. Jan Demuth	Federal Aviation Administration
Edward R. Jones, Ph.D.	McDonnell Douglas Astronautics Company
Cmdr. Norman E. Lane, Ph.D.	Naval Training Equipment Center
James J. Regan, Ph.D.	Navy Personnel Research and Development Center (Retired)

Sponsor Participants

John P. Jankovich, Ph.D.	U.S. Nuclear Regulatory Commission
Ellis W. Merschoff	U.S. Nuclear Regulatory Commission
Jerry A. Wachtel	U.S. Nuclear Regulatory Commission

Project Staff Participants

Patricia A. Bolton, Ph.D.	Battelle Human Affairs Research Centers
Robert L. Gruel	Pacific Northwest Laboratory
James C. Huenefeld	Pacific Northwest Laboratory
William L. Rankin, Ph.D.	Battelle Human Affairs Research Centers

APPENDIX B

CHRONOLOGICAL SUMMARY OF DISCUSSION AT THE MEETING WITH THE PANEL OF EXPERTS

Chronological Summary of Discussion
at the Meeting With the Panel of Experts

January 20-21, 1983, Denver, Colorado

The following summary is taken from notes made of the meeting. The discussion points are presented in the order in which they occurred throughout the two-day meeting. For the most part the identification of the speakers is not given. The reader can see Appendix A for a listing of those participating in the meeting and their affiliations. It will be noted that in general the background of the advisory panel participants is in an area other than the nuclear area, since the intent of the meeting was to draw on the experience available to the nuclear industry from other fields in which simulators have long been used for training and certification.

Session 1, January 20

Meeting opened by Bill Rankin (HARC).

Introductory remarks were made by John Jankovich (NRC):

- He noted that regulatory action is being contemplated regarding plant-reference simulators for nuclear power plants (NPPs). This decision will be based on current information; no new experimentation will be possible.

- The context in the industry now includes 30 nuclear power plants with the use of a simulator for training, and 35 operating plants without simulators, of the 75 operating nuclear power plants. Some of the plants with the support of a simulator do not have a plant-reference simulator, but typically will be using a simulator generic to the basic design of the NPP (e.g., Westinghouse, Babcock & Wilcox, etc.). Although many plants without simulators at the time are favorably inclined toward having one, not all feel this way.

- It is to be acknowledged that supporting statements cannot at this time be explicit and specific (e.g., cannot state: there will be a 5% improvement in . . .), but rather will be more on the order of general, although informed, statements concerning the expectation that certain elements of training and performance can be improved through the use of simulators.

- Three major questions must be addressed with the information available:

  (1) Should the industry be required to get plant-reference simulators?

  If yes,

(2) Should a required plant-reference simulator be full-scope?

If yes,

(3) How do we measure what is a plant-reference simulator? What are the acceptance criteria for simulators, including those owned and those to be built?

Jim Huenefeld (PNL) gave a brief description of PNL's project design for providing the NRC with the information it needs. It was established that INPO (the Institute for Nuclear Power Operations) would be in the industry review portion of the project.

A position paper authored by Paul Caro and previously submitted to the project staff was distributed titled "Simulator Training for Control Room Operators: Lessons Learned in Flight Simulation" (see Appendix C). Caro made a few remarks about the paper. He noted that the aviation industry has had many years to learn, or not learn, many lessons about simulator training, and these are applicable to the nuclear industry. The nuclear industry should not have to repeat the history of the aviation industry in this regard. He feels he has seen a resistance to simulators in some of the nuclear industry, and thus expects the industry to have many of the same problems. Not all Panel members agreed, however, that such resistance was evident.

A brief description was given of FAA requirements. It was noted that, with respect to heavy air carriers, the FAA specifies some required training as well as requiring pilots to pass the certification exam. In all other aircraft, only the certification exam is required for pilots. It is up to the pilot to get however much training he needs to pass the test for the license. Simulators are used for transition training (training for another type of aircraft) and thus a pilot may well be checked out on that aircraft during the first revenue flight taken.

In the nuclear industry, it is the law that the utility must train its people. There is a regulatory guide which states the method acceptable to the NRC. A utility does not have to do what the Reg. Guide suggests, but if it doesn't it has to set forth its own plan that is acceptable to the NRC. Following the accident at TMI, there was a letter put out by the NRC requiring the use of a simulator for the operation examinations. However, it was found that giving exams on non-plant-reference simulators was not very useful, and thus this requirement is not being enforced for those without plant-reference simulators.

It was noted that it could cost from about half a million to a million dollars a day to shut down a plant, which makes it costly, for example, to require operators to start up and shut down a plant during their training. The NRC has agreed that this could be done on a simulator, and then there can be a "check pilot" type situation when the operator first does a start-up on the plant itself.

It was remarked by others in the room that one implication of this was that it would cost from about six to 20 days to pay for a simulator, in view of an earlier statement that simulators probably cost about 8-10 million dollars (while plants may cost a billion dollars).

A question was asked about the existence of research to show that good quality simulator training can make a difference in plant efficiency. The NRC replied that there was not, and it was pointed out that (1) it was difficult to engage the industry in such ventures since they didn't like to have to talk about their mistakes to the regulator; and (2) the NRC's focal point is safety, and thus does not address the question of efficiency. When the NRC looks at benefits from some change, it is benefits in terms of health and safety.

Some of the types of research being sponsored by the NRC were mentioned:

(1) Since 1978 the NRC research branch has collected, using simulators, information on safety related operator actions. This research was begun to help decide at what point actions should be automated.

(2) Research being done into the number of people needed to staff the control room, and into what positions.

(3) Now the NRC is looking at the effect of the control room staff's education and training.

(4) In the Simulator Research Project, important factors for operator performance are being investigated.

(5) Training methodology is being studied with an aim to devising a method for evaluating training programs, not to developing them.

Research from the NRC's Office of Nuclear Regulatory Research which is relevant to the question at hand has been provided to the NRC's Office of Nuclear Reactor Regulation to aid in the decision on plant-reference simulators. Other possibly relevant research for the simulator requirement decision will not be available for 2-3 years.

Some of the reasons behind the urgency for the decision are that: (1) at the moment there is a problem with the equivalency of licensing exams for operators between sites with and without a plant-reference simulator, and (2) there already is a substantial number of simulators around and the more that are added to this inventory without standardized acceptance criteria, the greater the problem becomes.

At this point the discussion centered around the question of specifying a need for a plant-reference simulator. The FAA noted that, for it, the simulator has to be "plant-specific." It has to be validated against a known certified aircraft operating in the flight line. It can be asked, can we do training on something other than a simulator, and if so, on what? The aviation position historically is that full certification on a simulator is desirable. For the nuclear industry it is even more unrealistic to think of taking the unit out of operation to certify the operator. However, it is not really appropriate to ask whether or not NPPs should be required to have a certain kind of simulator; rather, one should first ask: what do you want the person to know (before asking about ways to learn it)?

Another point was made that it isn't possible to have the regulation until the technology is in hand. In reality, NPP simulators are somewhat crude compared to aeronautical simulators. It can be argued that the nuclear industry does not have a simulator of comparable value.

At the moment, NPP simulators tend to reproduce normal operations. More is needed with respect to failure modes and, in particular, interactive failure modes. This is an important dimension where the quality of a device is the issue. It is the case that there are incident records (Licensee Event Reports) from power plants, but they don't collect the information necessary to do models on a simulator. Some of the necessary information is available, but such things as onset cues, the nature of the decision process, and task analysis for what is done when things are out of tolerance are lacking.

It was remarked that initially the FAA had suffered from a lack of data, but they had entered into a "marriage" with the airlines to get what was needed for simulators. It was noted that lately the FAA has encountered pressures to back off from the most advanced simulator mode due to economic factors. Now the FAA is finding that it is lacking some kinds of data which would be necessary to do other things. They anticipate taking some time to get the data. And even with the advanced simulator programs, they are starting to go back to the beginning to refine them. For example, they are undertaking full-task analyses of the procedures for the type rating (which is the first step) to create a data base of a basic nature.

The discussion was moved to definitional issues. The position taken in PNL's Summary Letter Report was reiterated in the interests of getting reactions to it. Basically, the definition proposed was that of a two-dimensional definition of fidelity which includes physical and functional aspects, with the suggestion that psychological fidelity might be defined in terms of user acceptance. It was stated that settling on a definition would facilitate discussion during this workshop and would be useful for working out guidelines on fidelity.

The necessity of having a definition of fidelity was questioned, and it was proposed that the group talk about site specificity and about task specificity. Labels such as physical and functional fidelity can obscure issues, so it might be a good idea to stay away from them.

The discussion turned away from the question of a definition of fidelity. It was observed that when NPPs carry out exercises they seem to concentrate on emergency-related sequences. Is it that more emphasis is needed on being able to detect when the plant is getting out of tolerance? It was agreed that there is a need to teach out of tolerance conditions, but multiple failures (interactive failures) present the most difficult problem.

The question again was asked: What does an NPP operator need to be able to do in order to get certified? This was in an attempt to think of analogies with the aviation industry. For example, do operators have to be able to demonstrate the ability to start up and shut down the plant? And if so, is it necessary to have a simulator to do that?

It was observed that there were many kinds of situations that really could only be presented to an operator in a simulator and which were important, for example, in the view of the licensing examiners. The full-task exercise of an individual in an unknown situation should be part of the licensing exam process, was the opinion given by a person involved in the licensing process.

It was asked if the LERs (Licensee Event Reports) could be used to see if sites which used a simulator have a better operating record. It was pointed out that this probably isn't reasonable, since there are too many variables which could affect the operating record, such as type of plant, age of plant, conscientiousness in filing LERs, and so forth.

Another person pointed out that there are no two plants alike. It is difficult to find the original engineers to help with the design of simulators, and trying to find out what goes on in a machine already in the field is very difficult. Obtaining important technical data can be problematic.

It was asked if the NRC required the operators to demonstrate that they could perform a normal start up and shut down. The response was that start ups take a long time, maybe 12 hours, and that the time could be better used by both the trainee and examiner. The suggestion was made that it wouldn't be necessary to observe it, but to just require that it be documented. The point being made was that this could be a decision point with regard to simulators. If it could be demonstrated that even for a basic process (e.g., startup/shut down) that a simulator is the best way to provide the opportunity to learn and test it, then the question about emergency knowledge isn't even necessary. A simulator could be required for certification of the ability to do the start up, and then used by the utility for whatever other training it wanted.

Someone asked if it was even a question that simulators should be used for the licensing process (the examination process). Many seemed to agree that simulators are necessary for this and wondered why this issue even existed.

There was some discussion of the licensing exam process, both in terms of initial licensing and requalification. The procedure was described by one of the examiners present, and by the NRC.

An observation was made that the concept-based approach had been junked by aviation. There was now an effort to get a performance-based criteria for training.

It was pointed out that it is possible to get to the need for simulators from the training side or from the licensing side. If either part of the process requires simulators, the other part can be shaped by that and follow. It was proposed that the criterion for the training program should be: does the person pass the licensing task? Another person remarked that it probably is not desirable to have the NRC approve the training process itself.

It was observed that it probably is possible to get to a performance-based criterion in a number of different ways; that is, non-plant-reference simulators can be used for some training tasks, for bringing the trainee up to a certain performance base. Also, there are some situations in which the requirement to have a plant-reference simulator just isn't realistic for the plant, such as in the case of smaller, older plants, near the end of their life.

Session 2, January 20

The participants were instructed to keep two points in mind as the discussion progressed: (1) to think about the issue of simulators in terms of the use of plant-reference versus non-plant-reference ones; and (2) to think about the differences between aviation and nuclear power plants in terms of such things as criticality of response times and the degree of skill-based versus other skills involved in operation.

To this end, it was pointed out that in aviation feedback is rapid, but in NPPs the feedback is slow, being in terms of minutes or even hours. There are a number of options available to an NPP operator in a specific situation. (Further consideration of this point by a Panel member prompted the observation that, on the other hand, much aviation experience these days is very similar to that of NPP operators in that many flying tasks are fully automated and malfunctions often lend themselves to prolonged management or problem-solving attempts in flight.)

There was some discussion about what was done when a simulator and an aircraft are not the same. The FAA requires that the simulator be tested and approved for each variation in the set-up. Another person observed that a well-designed simulator can be flexible, i.e., can be such that some physical aspects and all the software can be easily changed. If a simulator is designed from the beginning for this type of flexibility, it is easy to do such changes.

At this point there was a discussion about the implications for simulator design and for examination requirements for the instance of mirror-image control rooms at one site. In the one case where this exists, operators are licensed to operate both plants. The concern was that in the situation of general similarity, but with display and control location in one control room being just the opposite from that in the other would increase the likelihood of operator errors. There was discussion of what kinds of differences from one setting to another (e.g., from a simulator to the operational control room, or between control rooms at a multi-reactor site) make the most difference in operator error and would take special consideration. If a plant-reference simulator is required for either testing or training, the question is how can it be specified for a situation when mirror-image control rooms exist? It may be possible to make adequate adjustments in training and in the evaluation procedure to assure that operators are equally capable on more than one control room? On the other hand, such adjustments may not be adequate. This situation was felt to warrant more research. Then the discussion moved back to comparisons of the industries.

It was suggested that there was a need for some other parameters in order to make the problem manageable. There is the example of the FAA that has a certification process where they can declare they won't certify specific things. Also, a process could be designed for bringing in experts to resolve specific issues at various points in the certification process.

Risk was proposed as the really important issue. This was restated by another as: how can we certify and train operators in such a way that this will have an effect on error and on its reduction? What kind of training or simulators must there be to reduce error? It is probably the case that we cannot specify how much error, but we can talk about it in terms of cumulative effects, etc.

The point was raised about the legal angle of plant-reference simulators and the possibility that a plant could be sued for having not used state-of-the-art methods and devices in training, were there an accident.

The question was raised about what to do with criteria for simulators already in existence and for new simulators. There would be argument about whether there needed to be a grandfather clause, for example. Older plants won't want to put the expense into a simulator, or into a different one from what they have. There was at least one opinion that even though the economics will be different for existing simulators and new ones, it will be important to make requirements similar. But we can think in terms of risk factors in doing this. It was observed that plants differ in size and design and the risks differ. Many of the current regulations tend to refer to the big plants. In aviation, smaller commuter carriers aren't held to the same training criterion. The suggestion was made that there could be more requirements placed on some plants to compensate for their inability to meet certain guidelines.

There was some brief discussion about the use of part-task simulators to supplement the plant-reference simulator in training. For example, the use of SPDS (Safety Parameter Display Systems) may be prepared for on part-task simulators. The SPDS wouldn't be on the main simulator, but they would need to devise a system for training for it.

It was pointed out that it is important not to lose sight of the question of how to deal with being sure that NPPs know how to make the best use of simulators.

A reminder also was voiced that there is the need to separate evaluation from training when discussing simulator criteria.

It was pointed out that basically the FAA certifies training programs. With respect to the simulators used, the FAA does approve a simulator to use for certain levels of training, which then allows the simulator to be used for training for specific maneuvers rather than the aircraft. The airlines tend to choose to have simulators for their training programs because they are cheaper and easier to use than operational aircraft. The NRC should certify training capability and certify trained performance, but not certify simulators. Licensing exams should be structured so it can objectively evaluate performance. Then, if NPPs can get their operators to that level of performance without a simulator, that is acceptable. It was observed that there is an important philosophical difference between certifying a simulator and certifying a training program, since simulators don't train, they just sit there.

The discussion turned to the licensing process. It was observed that it is somewhat of a problem at the time, in that it doesn't appear to be very objective. There is a need to decide what operators need to know and to arrive at a way to evaluate when operators know these things. The NRC system now doesn't really do this. The example was given that the FAA has defined what is a standard operator, and then one has to train for that. It is important to have a standard operator defined to the point that one can then define what media will produce this standard operator. It was observed that there is a move in the nuclear industry to do that, and even though it is not possible to wait for the data from that effort, it is believed that those data will point to a plant-reference simulator as the medium. Then the question was posed as: Do we need to evaluate the operator in a full-task environment? If so, does this imply a plant-reference simulator? The observation again was made that the NRC guidance on training programs should not be mandatory, but permissive. What is needed is regulatory requirements that state what the operator must demonstrate to obtain a license.

Session 3, January 20

The discussion initially dealt with the utility and adequacy of simulators for examination purposes. It was asked if there was efficacy in the use of observation of operators in full-scope, full-task situations as the basis of the examination. At least one person was of the opinion that observation was not good enough. It is true that there is conjecture about the use of subjective measures, and that although they seem to be important, they are not as reliable as they should be. Engineering simulators can provide a lot of information about what was just done (e.g., what response an operator made) and in the evaluation of performance one needs to take the position that quantitative as well as qualitative information is necessary. Another way of putting it could be that if you don't care about high reliability, you can use subjectivity in evaluation. The opinion here was that the exam process should produce reproducible data (e.g., performance monitoring system data, checklists, video recording, etc.) and avoid subjective decisions. Any examiner should reach the same decision based on the information produced. Another person added their endorsement of reliable and objective measures, but said that the sensitivity of the test also was important. One Panel member added at a later time that some aspects of the evaluation are lost when the human observer is removed from the situation, such as recognition of the interplay of operators in the situation. Also, there is the consideration of greatly increased costs of many of the techniques used to eliminate subjectivity as much as possible.

There was some brief discussion here about teams. One person observed that research from Ames indicated that there was a lot of variability among teams with respect to evidence of the existence of team integration. In the NPP situation, there isn't crew integrity in the control room (i.e., the same persons don't train and operate together always), the implication being that variability would be even greater among different crews. Another person observed that task analysis probably would indicate there are tasks that are team tasks (the implication apparently being that this would raise a question about the need to examine for them).

There was a brief discussion on stress and its importance to the exam situation. It was observed that research indicated biological indicators of stress levels were identical for persons operating in simulators and in real life (in aviation research). One opinion with respect to the question of the effect of operating under a stressful situation was: if a person can operate a simulator under stress, he may or may not be able to operate the plant; if he can't operate the simulator under stress, he can't operate the plant under stress. (Note: The role of the simulator in improving performance under stress is further addressed in Appendix C of this report, Caro, Simulator Training and Anxiety.)

The question was again raised about what is it the NRC expects the operator to be able to do since this would be what you would look for on the exam. It was suggested that the task analyses being done by INPO and NRC at the moment might help to define this. The question was specified further as: Is it at least possible to say that there are things that have to be done on a full scope simulator for the exam? Can the job task analysis be expected to reveal some such things? One observation was that a job task analysis won't produce a description of the cognitive things that go on in an emergency situation. Another person noted that some things will have to be obtained as part of engineering data; they won't be revealed in an interview about tasks.

There was some discussion of the identification of abnormal and emergency procedures that it would be important to know. It was observed that it probably wasn't desirable or possible to practice on every eventuality. It will have to be hoped that certain practice will transfer to other eventualities. A minimum limit of things to practice was suggested, and also that there could be a list of things that are considered critical (due to their criticality, frequency, etc.). However, the NRC would need to allow flexibility in such a list, because things are always changing.

It was observed that the English use a procedure in examination of telling the operator what the event is, and then covering the gauges and asking him what information he wants in order to solve the problem. It was stated that the oral exam in the U.S. had something similar to this, but it wasn't clear that the procedure really distinguished among examinees.

The further question was raised that if it is accepted that the operator will be able to generalize to other events after practicing some, how many interactive failures do you need to practice with? One position was that it is an empirical question, although a difficult one. It could also be added that total ignorance breeds total simulation.

An inquiry was made as to how many malfunctions the FAA uses. It was pointed out that the first question is about knowing what the set of things is that you want the operator to do. And if you say that he has to be able to handle two simultaneous events, then the simulator has to be able to do it. The air industry does five levels of compounded failures.

It was pointed out that the TMI reports specified the inability to handle multiple failure as a problem. There are some things that will be needed from the job task analyses being done, but these analyses may not emphasize these enough. And at the present time engineering data are not adequate either to provide the information.

The observation was made that criterion-based performance is preferable over "norm-objective" based behavior. It is probably desirable to set a level to which the person should perform; that is, to set parameters or values the operator should meet rather than set a score for overall performance. The question was asked about what kind of data are available on which performance-based criteria could be developed--for example, from task analysis or by drawing on what examiners are using? One opinion was that these things will come from the examiners rather than from job task analysis, and that there probably is actually quite a bit of agreement among the examiners as to performance requirements. A suggestion was made that it might be possible to ask examiners what scenarios they would require on a simulator to find out what they want to know when evaluating performance.

It was stated that the FAA's set is evolutionary. It is administered by putting an evaluator in the loop. The pilot's union was against the use of only objective data like a ground path or a PMS (Performance Measurement System). The pilots wanted a peer evaluator in the situation as well. So the process uses both pieces--advanced simulation and peer evaluation. The question is, can you watch a man perform on a simulator for a specific scenario in lieu of watching him perform the real thing?

There is a move toward letting the simulator be used for the evaluation, but there still is a man in the loop. Task analysis may reveal that the FAA can do the evaluation in something less than a full-task simulator, but that still isn't known at this point.

It was observed that research that would look at each evaluation approach independently and compare the two would be interesting.

It was noted that operators may think they don't want too high a degree of objective measurement, but there is a "protection angle" to it too, in that they also get protection by having passed an objective simulator exam. It acts as further assurance that they can do their job correctly.

It is possible that some of the negative feelings toward the use of simulators in evaluation come from persons who have had experience with bad simulation. They often become critics and antagonists. This is a problem. If the data in the nuclear field are still bad, it isn't possible to get the test data needed. An operator needs to know that what he sees on the simulator is what he would see in the plant. If the operator can find a "short-cut" on the simulator, he will lose respect for the simulator. There also is the danger that he will practice the short-cuts rather than the potentially dangerous situation in the manner it would unfold.

The observation was made that for now on normal routines, simulation is pretty good. But it may not be as good for abnormal events. Operators will say that that wasn't how it was when they saw it for real (although for the most part, operators have never seen most events for real).

The discussion turned to the price of good simulation, and what creates the price of simulators. Basically, the price should be "spec-derived"; that is, the purchaser produces specifications and manufacturers bid on providing that equipment. With this system, the utility should get what it specifies and pays for. The simulator then will be only as good as the specifications provided. The opinion was stated that the NRC had the responsibility to know what simulators should cost if they require them. They will need to be able to argue from a strong grounding in the technology about the value of simulators, to help assure that prices don't become artificial.

<u>Session 4, January 20</u>

The discussion initially was directed toward the question of the functions that simulator instructor stations need to provide. It was observed by one participant that in his experience after you decide what the simulator is to be designed to do, what goes into the instructor station falls into place. A list of the features that should go into an instructor station is not the point. There are many examples of how to build bad ones, of course. And it is possible to design a simulator so badly that its use as a trainer is reduced. The objectives for and design of the simulator should lead.

The need for instructor training was brought out. It was noted that there are lots of simulators out there that nobody knows how to use. To decide what an instructor needs to know, it is necessary to decide what it is they are supposed to teach. It can be asked if an instructor is needed. There are such things as instructor-less trainers, or automated systems, which can be used without an instructor. These might prove useful, since in some instances the instructor can be a problem.

With respect to what goes into an instructor station, the background of instructors was cited as a point of design difficulty in some circumstances. For example, some instructors want a display just like the aircraft, while other instructors want an integrated display.

It also was pointed out that the character of the station for training and the character of the station for the evaluation of behavior may be different. The items listed on a handout for the meeting (e.g., fast time, slow time, freeze, recall, etc.) could be characterized as useful for the training function for the most part; for evaluation one might want the option of a PMS (Performance Measurement System).

With respect to what the station ought to have for evaluation purposes, it was asked if it might be possible for the licensing examiners to specify this. Would it damage the training program if the evaluation needs took the lead in instructor station specifications? It was observed that asking the examiners was as legitimate a way as any, but like any other approach would have limitations; it would affect the situation. Having a flexible minimum was proposed, since it is a given that a decision will be made; it is important to try to keep from making too many bad mistakes.

Some of the other things that must be considered for a station were mentioned: what does the instructor need in the way of a console; does the instructor need video recorders; how many instructors will there be; will instructors want to sit down, walk around, or both? Often current simulators have been badly designed for training, and are difficult to use, from the instructor's standpoint. It was repeated that what is needed from the regulation viewpoint (for licensing) and what is needed for instruction will probably differ. Also, if it is wanted that a simulator provide performance information, that will necessitate certain things; if examiners will sit and watch, that dictates a different design.

It was suggested that there are methods for deciding what should go in the instructor station. For example, it is probably possible to make up a list of what examiners need by talking it over with examiners. It won't be possible to just say, "You need a performance measurement system." The industry will then ask what this means, or if what they have qualifies as a PMS. But minimum acceptable requirements should be all that the NRC makes.

It was suggested that when an agency is going to regulate, it should look only at the performance output. It wouldn't want to get into the design business. It was observed, however, that the nuclear waste law passed in

December has a clause in it which says that the NRC has to regulate training. In instances such as this it is best to leave it fairly vague. For example, one can put in the law what is an acceptable minimum, and then cover the rest with a Regulatory Guide. The Reg Guide provides a method for meeting the problem, and provides the industry with the option to offer a different method that it feels is equally defensible. The need to regulate training in the future calls for a bringing together of nuclear training specialists and simulator specialists.

A conference, sponsored by ONR and held in Orlando in August of 1982, was mentioned as having provided differing viewpoints on simulator attributes.

It was proposed that this group could provide input to guidelines for training. What currently existed was noted to be ANS 3.1, 1971, which was the last American Nuclear Standard on training to be endorsed. The 1978 and 1981 versions have yet to be accepted by the NRC, it was observed. It was pointed out that licensing really is the hammer that the NRC has so that perhaps is the more important issue.

At this point it was proposed that the discussion be brought to a close for the day. It was stated that there seemed to be at least three important points which could be gleaned from the day's discussion. (1) It was felt that the discussion indicated agreement on the need for plant-reference simulators; (2) if there is going to be a plant-reference simulator at each plant, there probably is not a need for part-task simulators to be required. That is, if you have a big simulator, no others are needed except to the extent that they might be needed in specific situations to fill out training needs due to time constraints on the big simulator, for example; and (3) it appears that it can be specified from the licensing viewpoint what is needed on the simulator, but that won't be the whole picture. However, further technical analysis is needed to better flesh out the whole picture.

It was observed that the group never had addressed principles simulators. A brief discussion of them indicated that principles simulators could be used to teach certain cognitive performance, but that they are not useful for training specific tasks or for licensing evaluation purposes.

The question was raised as to whether or not it really had been specified why the group seemed willing to agree that plant-reference simulators were needed. Certainly the implication of several of the different discussions pointed to plant-reference simulators as desirable in view of the data base and the facts of the operating contexts in the industry, but a more explicit specification was suggested as desirable.

Some discussion ensued at this point. The position was that since there isn't really a great deal known about the process of what and how best to teach and examine NPP operators, the best approach is to go for the truest to operating conditions possible. It was proposed that the reason, however, for requiring plant-reference simulators do need to be comprehensive, complete, and persuasive. This is not difficult since the arguments for them are based on knowledge about human performance, the learning process, and so forth. There is documentation of this. It can be contended that there are data and theory to indicate that plant-reference simulators are necessary. However, it must be noted that simulators can be plant-reference without being full-scope, for example. It was proposed that these issues be taken up the following day.

(Meeting was adjourned for the day.)

Session 5, January 21

A set of issues was proposed for consideration in the remaining time. These included: stating in more detail why plant-reference simulators were considered necessary; fidelity and scope issues for the simulators; rules for exemption; guidelines for plant-reference simulators; pitfalls of requiring plant-reference simulators; how to minimize the "it's only a simulator" syndrome; guidance for "user acceptance"; and model training programs.

The discussion began with statements from several of the participants concerning reasons for plant-reference simulators. It was noted that several of the arguments are provided in the paper on lessons learned in flight simulation (see Caro, Appendix C).

Various reasons justifying the presence of plant-reference simulators at NPPs were given. These included that operators want them and that there are legal considerations, in that it would be better for a plant to be defending itself after an accident situation if its training had included use of a plant-reference simulator. From a scientific basis, it can be held that the training situation and evaluation should present operators with the possibility of defining precise alternatives, followed by precise motor responses. The plant-reference simulator is better for preparing for this. In training it is important that feedback be not only immediate, but precise and appropriate to the situation. Plant-reference simulators make it possible to observe the operator in a realistic situation, making it easier to evaluate him. It also is probably true that plant-reference simulators greatly eliminate the possibility of negative transfer from the simulator to the plant. Although rule-based behavior is the most frequently used by NPP operators, it can be argued that skill-based behavior is important as well, and plant-reference simulators probably better assure the transfer of that behavior. Furthermore, the existence and presence of a plant-reference simulator might well lead to more practice because of the impetus to use the simulator, now that the plant has it.

Another participant concurred with the above positions, noting that with respect to the legal issue, the plant that does not have a plant-reference simulator is legally defenseless when the option to obtain such a device was available but not exercised. Also, psychological theory can be made to support the theory of plant-reference versus generic simulator use. In general, the best reason is that having a plant-reference simulator might save the plant, in terms of better, more proficient operators being able to avoid a TMI-2 type situation. These simulators can provide training which results in better operators. One can't train someone to operate a complex system without giving him specific training on that system. It is possible to make a one-to-one transfer if the simulator is well-designed. And since there are some tasks that must be simulated if they are going to be trained at all (because the plant can't or wouldn't be used) a simulator is necessary. This doesn't necessarily mean a full-scope device (although that is desirable). It would be possible to use a family of part-task devices, but they must be plant-specific, even if they are two-dimensional paper trainers. The "sort of like" case in training is probably the worst. Indeed, it is difficult to think of a place where one could argue for less than plant-reference. It might be possible for general education, but the operator cannot go from that general education to a plant that is different. If generic devices are being used, there still will need to be a specific stage in between that and the actual plant system. Also, it is easier to train on a plant-specific device. If a non-specific device is being used the instructor has to compensate for these differences by talking, for example. The often undisciplined nature of training programs at many NPPs suggests that the successful implementation of complex training situations is unlikely. The best training devices possible are needed, to reduce the need for relying on instructors to provide adequate compensatory instruction. Currently, about 70 percent of simulator training is accomplished on generic simulators (so compensatory instruction would be in order).

Based on reasons such as those outlined above, many knowledgeable people have come to see a need for plant-reference simulators. When requiring plant-reference simulators, the position can be taken that they should be high fidelity unless there is some specific evidence that can be applied to a decision to back away from high fidelity. It might be possible to back away in training, but this is not true with respect to the assessment of proficiency. On the other hand, there are some problems that have to be faced. Right now most of the simulators in use are not very good, and the instructional facilities often are poor. There is not a good ability to introduce the right abnormal events, cue patterns, interactions, complexity increased further by human error, and so forth. Human error considerations are hard to quantify on a generic simulator. Also, there are not good provisions for recording the responses of operators. The industry really is in a catch-up mode. They are going to have to go back and revise. That will be hard, but the simulators cannot really be perfected until you know what you need. And there is the quality of use problem. The way a simulator is used is very important in how useful it is. Annual plant reviews that INPO does, for example, on instructor programs are useful. NRC can take a role in that.

It was noted that INPO had completed 15 separate task analyses. They are generic and are to be taken and applied to the specific site and tasks there. These will help. The FAA provides "regulation by objective." There are basic requirements and the airlines can design training to meet these. If the requirements get too specific, they are hard to meet. One can argue for generic and flexible task analysis in this sort of situation.

It was pointed out that there still are antecedent questions. From the training program perspective, there is a lack of similarity in training. And there is a need for practice. Plants need simulators to provide for training similarity and practice. If a training program requires simulator training (and it appears that for NPPs, it would) then plant-reference simulator training is crucial.

The type of people being trained is another consideration. They for the most part are high school graduates, for example, not college graduates. It can be argued that it is less important to train on principles. Principles are picked up over time, but they are not necessarily needed initially, and the doing of the tasks is what is important.

One of the airline companies was described as having gone to a training stance of teaching "what to do in this instance." The training is oriented toward the mission. Now the pilots have complained that they don't know enough about what they are doing, in terms of aeronautical theory, but when pushed, they could not cite specific instances of where a lack of such information had caused them a serious problem. They knew what to do, even if they did not always know why.

With regard to the status of NPP operators when compared to pilots, the airlines are seen as treating pilots in a first-class manner and getting very professional responses in return. When operators are not treated in this way, one might expect response in kind.

It was pointed out that NPPs are running about 10-15% deficient in staff. There is pirating of operators going on, and operators are looking to better opportunities in European plants. So there are lots of personnel problems to be faced. Training programs get pressured to get people through and onto the line. This can lead to a situation of pushing operators out into the plants too soon, because they are needed there. Then the necessary on-the-job training is not that well taken care of. There is a danger of "forcing" operators into the control room before they are fully trained.

The discussion moved back to training and evaluation. It was noted that it isn't really necessary to go too far with specifics and explicitness. The airlines used to be more specific in their training than was necessary, in one person's opinion. It was observed that readouts (of pilots' responses), for example, are not necessary if there is a man watching and evaluating. But if a record is needed (e.g., for legal purposes) then a readout is desirable. When a person's performance is being checked, it better be a check of what they are going to do. People will train for what they anticipate being checked on. Some training probably can go on in a generic situation to some extent and accommodations made. Would it be possible to put together a list of what is generic to plants and use that? Can consideration be given to use of difference training, where things are not the same?

There was agreement from others that there may not be a need for full-scope, high fidelity devices. A family of devices can be used, for example, but it has to be designed toward specific training purposes. A course of incurring unlimited costs for devices without consideration of training objectives is not a reasonable course.

It was pointed out that there are critical elements in operations and other things less critical. It may be possible to back off on some things with regard to full fidelity. However, another person felt that the simulator must be as similar as possible to the plant. Added to this was the comment that there is a lack of enough information now on what is critical, so it is necessary to err on the side of conservatism. We just don't know what to leave off at this point, even though it is likely that some things can be left off.

Another aspect is the need for team training where teams are involved. It is possible to use part-task trainers to train skills, but at some point it probably is necessary to bring the other people into the setting. There are implications of this for scope.

It was pointed out that there is still a need for risk analyses incorporating fault trees, for example. The TMI-2 accident might be considered analogous to the DC-10 pylon accident; they didn't think it could happen so they didn't train for it.

It was stated that a remark had been made that there are a lot of simulators in closets. Why are these simulators in the closet and not in use? Can we gain insights from this? The first reason offered was that instructors are not good and don't know how to use them. The biggest pilot complaint about specific simulators is, "It doesn't fly like the airplane." When introducing simulators it is important to be careful not to generate a situation that will create negative impressions of simulators and thereby increase the difficulty of getting them accepted in the long run. There is a need to do more than meet the specifications for the simulator; there is a need to tell people how to use it. (The participants returned to this discussion later in the morning.)

The observation was made that training should be included in the report to the NRC. INPO is trying to decide what is needed and preparing a manual. The plant evaluations done by INPO were described and discussed.

It also was observed that the purchase lead time for a simulator is probably something like 24 to 30 months. INPO can help with purchase and training improvements during that time. There is a need to address the lead time problem in the report to the NRC.

The Airline Transport Association (ATA) and its relationship to the FAA was depicted as analogous to the relationship between INPO and the NRC. The ATA experience would suggest that the utilities should try to meet the NRC wishes before more stringent requirements are put forth.

Session 6, January 21

It was observed that there seemed to be a necessity for job task analyses to be done. In lieu of these at this time, it is reasonable to make the preliminary conclusion that: (1) job task analysis probably will show that plant-reference simulation is necessary; and (2) with regard to the scope of simulators, it is best to err on the conservative side.

The participants were asked to address the question of what "replicate" means. Would saying a simulator is plant-reference mean the same thing as saying it is replicate? It was observed that the FAA sees a simulator as by definition "replicate"; anything else is a training device. The discussion turned to an attempt to define full-scope, and then went to the notion of simulator acceptance. The research indicating that research on procedural tasks has shown that the training medium can vary considerably and still be effective was noted.

A need to define accuracy was stated, and accuracy levels were discussed briefly. It was noted again that basically there are normal operational data for establishing simulations, but there are not adequate data for designing good out-of-tolerance simulations. With respect to the question of how to make a simulator "feel right" it was questioned whether or not this was as difficult to do for an NPP as for aircraft.

It was asked if it was reasonable to declare the fidelity of a simulator as adequate if the utility found it acceptable--that is, could user acceptance be used as a criterion for the psychological fidelity of a simulator? At least one person did not consider this a good idea.

The alleged resistance to plant-reference simulators was asked about. It was noted that, for example, small, older plants are not willing to make such an investment at this stage in their life cycle. The suggestion was made that some exceptions could be made possible. They could be written into the requirements. On the other hand, it also is important to be careful to not bend too much to older plants. At a minimum it is necessary to attend to requirements for current and future simulators. It is important to make sure that the same problems not be created again, down the road, when current plants are old. It was observed that the older plants might need simulators the most, if they are the most prone to abnormal events. Those operators need the most training and practice perhaps.

The observation was made that the Human Factors Society report had said with respect to simulators that the NRC should certify simulators; the Panel of Experts at this meeting appeared to take the position that it was best to certify training programs, not simulators. It can be noted that this parallels aircraft training.

The discussion was again turned to the reasons for simulators being in closets--that is, not being used. Some are old ones that either never were good, or are no longer applicable. Also, the military allows the individual commander to choose, and thus simulators which exist may not be used because of the view the commander takes of them. Poor design is a factor in lack of use. Performance may not have been good enough that they were ever acceptable. Or instructional features may have been too bad to allow them to be useful. Both lack of a management requirement for efficient training and old devices contribute to the lack of use of some simulators. Simulators may have been found to be too restrictive in scope. One way of putting it is that poor purchase practices lead to lack of use. Also, simulators that persons feel have been forced on them may eventually come to be rejected due to negative feelings about them.

With respect to the situation of bad simulators, it was stated that users have to demand and expect good simulators to get them. At the present, this isn't really the case for the nuclear industry and so they may not be getting good ones. Bad simulation creates negative feelings about simulators, and the cycle continues. The industry needs to have its expectations raised about what can be gotten in the way of simulators--although it also has to be realistic. The industry has to be educated as to the proper use of simulators. And it needs to develop good training people in order to best use the simulators. It could be asked who could take the role of helping the industry with these things.

Currently there is a lack of instructional devices in general in the industry, and a lack of good instructors. The simulator and the training program is only as good as you make it. It was noted that the quality of simulators differs between vendors, and also that simulators may only have about 15 years of technological usefulness.

At this point the discussion was guided to the question of what might be some of the pitfalls associated with a requirement of plant-reference simulators.

The first caution was that because of the limited sources there are for supplying simulators, there is a need to look at the whole impact of requiring plant-reference simulators in a balanced fashion, making it possible that the price could go up substantially. Again, the advice was voiced that the NRC should know what simulators should cost. The cost of simulators, of course, extends beyond the delivery cost. There are also spares, calibration equipment, shop space, instructional staff, maintenance staff, life cycle costs, personnel impact, and so forth. It was stated that there is no use in buying a simulator without buying (or developing) a training package for it. Probably 8-10% of the cost of the training package is for development and installation of the training program (including instructor training). And there are certain costs associated with the students (although this cost may be in exchange for costs now incurred to send students away to training centers).

One suggestion was that the NRC not become too prescriptive, for this can cause many kinds of problems for it.

It was asked if there are data on whether simulator use reduces accidents. It was noted that the airlines now don't take planes up for training so the risk is removed, and there are no comparative data.

There is concern that if plant-reference simulators are required, utilities will just use their old training programs as they are and plug the simulators into them. One problem, thus, is limiting what goes on in a training program. Good training programs are important for making good use of simulators.

There was some discussion of who might be the prime suppliers of simulators, and of costs of various kinds.

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The topic posed for the afternoon was that of model training programs. It was noted that several systems exist for designing such programs, and they are not as expensive as you might think. But it is important to do your front-end homework. Also, it is true that good training costs money. Good training consists of far more than a training device.

It was asked if the NRC is in a position to certify training programs. Apparently that sort of thing is seen as being several years away. INPO is working on some aspects of it already, however.

It was observed that it is one thing to certify and approve an offering in the way of a training program, but it is another to specify what should be done. The FAA is limited in what it can require; by law it can only require evaluation. The FAA will "bless" a training program, but it does not put forth any particular requirements. Its approach is to define an end product that puts the responsibility on the companies to develop training to reach it.

The statement incorporated in the Nuclear Waste Bill which says that the NRC will require training programs, simulators, and drills was read. It was remarked that what is in that bill is very broad and it isn't clear what it will include.

It was pointed out that there will be enough time between when a utility orders a simulator and when they get it to develop a training program. (Not everyone present agreed.) Also, if the NRC is requiring plant-reference simulators for licensing, this will drive training program needs.

The general process for designing a model program was set forth. The basic steps are: (1) statement of objectives; (2) statement of alternatives; (3) selection of alternatives; and (4) implementation of alternatives. In developing programs it is to be expected that it is an iterative process.

The difference between requiring a process or setting standards was observed. It was stated that we are talking about process. However, the need to concentrate on the outcome, and not the process to get there, was brought up again.

It was suggested that we can easily state that plant-reference simulation is necessary for evaluation. This will drive the training program. Then it may be necessary to specify who needs simulator training and how often it must be done, for example. And it will be necessary to specify to whom this task would fall.

There is the issue of the standardization of exams. That will be bounced back against the training. There is a need to define a minimum set of procedures, and to address the frequency issue for requalification testing, as well. An airline might do it once a year, for example, but the pilots also get practice in many aspects of their job on a more routine basis. But determining how often one is going to be assessed is going to drive how often practice is given.

The question was raised as to whether or not the FAA was experiencing personnel constraints on the frequency of assessments. It was stated that at first there had been no problem, but lately it has been creating one and they are developing a system of designees [sic]. The initial rating always is done by the FAA; requalification can be done by designee.

The point was brought up that the regulation might not be credible if it leads only to training for the examination specifically. But there is a need to figure out a way to guide the training without directing it. Licensing can play an important role in guiding training.

The suggestion was made that ISD, or some variation of it, could be promoted. The opinion was given that there is nothing wrong with the ISD model, although there are problems with the way it is used in some cases.

It was noted that there are "life stages" in program design, and they are iterative. They include: design, production, utilization, evaluation, modification, and update. It was observed that power plants change a lot. This is not so true in aviation. So updating is a bigger problem with training program design in the nuclear industry. There must be coordination between that which is trained and that used in operations. It is possible to get the two separate development efforts out of synch if one is not careful. The FAA has a single group handle both rules for operation and the "blessing" of training packages. Also, the development of procedures is a good way to keep on top of changes.

The need to think about the acceptance of the training program was pointed out. It may not be reasonable to think that a program developed in one place will be acceptable or useful elsewhere. There is a need to include user involvement in simulator training development. Operators should be included. There should be a team responsible for the development, which will be able to work on all angles.

A standard for evaluation checks was suggested as important to have. It would be possible to look at the amount of training it takes to get passed. If it is assumed that the exam is good enough, then it is possible to look at what it takes to get everybody through it. It was observed that failure rates have some validity. If the exam is standardized, one can evaluate training programs this way.

It was suggested that training is like a production line. It is a process. There can be checkpoints along the way to assure quality. There has to be a quality control function embedded somewhere that is separate from training.

Recurrent training was brought up. For airlines, it is believed that evaluation should be done often. When evaluations are done often, recurrent training is done more often. Recurrent training is an evaluation process, but in a training environment. A pilot could fail the recurrent training. The FAA has okayed that frequency of training (at least for one airline). There is an FAA approval program on frequency and content. There doesn't have to be an FAA witness there. The FAA can check the check airman. The airlines are responsible for administering the check program. So the NRC could say, for example, "We reserve the right to check your people. You have to do such and such with this frequency. We will spot check individuals and programs." The FAA checks check pilots yearly, and it tries to do an annual proficiency check on every pilot. In the proficiency check, a landing has to be more than successful, it has to be done right and in a good manner. A license would be pulled for a bad landing. For the proficiency check more stringent evaluation standards are used, and it is done under a real situation. In the Line Oriented Flight Training the pilots are subjected to complex scenarios and they just have to get through them. During the proficiency check, they must perform more routine functions correctly and smoothly.

It was asked what might be the pitfalls with establishing minimum standards but with exams done on a subjective-consensus basis. This is in the case of having a replicate simulator. It was observed that there may be an impact on the limited manpower situation. It may tax the manpower resources for training, for example. This is especially true for plants that now have very limited training on site. Some plants don't have a training section, but if they get a simulator, they will have to have a training section.

With respect to simulators used for the licensing function, it is possible to define a functional set of standards for the simulator on which an operator can be tested, without causing problems in the training program. It was observed that the FAA defines a benchmark when it sets standards. This should be beyond what is wanted and needed, in case people are designing to meet just that and no more.

It was pointed out that it may be possible for the NRC to set requirements that take effect in the future, in order to buy some time. The initial standards can be set. Then by the time the utilities develop their programs and come to ask if they are okay, there will have been time to do further work on what is acceptable.

It was asked what might be the consequence of the NRC never coming out with a guide. It was remarked that this would result in a loss of consistency across the industry.

An advisory letter was suggested as a method. First, it is necessary to estaolish standards for maneuvers and procedures. But that is not all that complex to do. Also, there is a longer fuse for guidance for training than for licensing.

(Several people had to leave at this point. The meeting was adjourned.)

APPENDIX C

UNPUBLISHED POSITION PAPERS ON THE TOPIC OF SIMULATOR USE

SIMULATOR TRAINING AND ANXIETY

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One characteristic of training in a simulator, as opposed to training in some operational equipment, is that simulator training is not life threatening. Consequently, the high levels of anxiety that can occur in inherently hazardous operational situations such as flying a tactical aircraft or operating a nuclear power plant are less likely when those hazards are simulated rather than real. Nevertheless, some persons have raised objections to simulator training specifically because it is not dangerous.

An assumption underlying such objections is that the anxiety associated with operational performance, commonly called the "pucker factor," affects what is learned and the strengths of the skills that develop. More specifically, it is assumed that one cannot learn the skills sufficiently well to ensure adequate operational performance unless the learner is exposed to "real" job stresses. However, this assumption fails to recognize the difference between acquisition of the specific operator skills that will be needed and learning to employ those skills in anxiety inducing circumstances so that their performance will not be disrupted by the anxiety. Given this distinction, two questions may be posed: Is anxiety necessary to the learning of the specific operator skills involved, and if so, in what amount? In answering these questions, it should be remembered that the amount of disruptive anxiety experienced in operational performance generally will be inversely related to the degree of skill mastery at the time of the performance.

The reduction in anxiety possible when training is conducted in a simulator can have a facilitative effect on learning, since high levels of anxiety have been shown to interfere with the learning process. While even low levels of anxiety are not necessary to learning, they can be useful. Low anxiety can maintain states of arousal and can provide motivation to the learner.

Anxiety is not required to maintain arousal and motivation. In a learning environment, arousal can be maintained--and usually is--through other means. For example, the desire to succeed brought to the training situation by the learner, the design of training equipment and programs to incorporate aspects of the operational situations, the skills and knowledge of the instructor, the intrinsic reward system associated with a particular training program, and the expressed attitudes of management toward training in simulators all serve to maintain trainee arousal and motivation.

These other means of maintaining arousal and motivation can provide the intensity of concentration characteristic of high levels of anxiety, and hence help prepare the operator to confront anxiety inducing situations. For example, experienced pilots flying simulators have been known to exhibit both behavioral and emotional responses to simulated abnormal and emergency situations that are quite similar to those exhibited under stressful situations in actual flight. When the simulation is effective, i.e., the simulator corresponds to the aircraft and its use is well structured from the instructional standpoint, it becomes fully believable, and the responses of the pilot in it are strikingly similar to his responses in the aircraft.

Concern over absence of the "pucker factor," i.e., the anxiety thought to be associated with a life-threatening training situation, has been voiced primarily among personnel whose experience with simulation has been limited to generally poor quality simulators and improperly designed or administered training programs. As the quality of simulators has improved, and as personnel have gained experience with these devices and have learned to use them more effectively, these concerns have been voiced much less frequently, if at all. The belief that training in a device just cannot be as good, qualitatively or otherwise, as training in the real life situation where the dangers are "real" does not prevail when there is critical examination of the effectiveness of good quality simulator training.

REMARKS ON FIDELITY

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Fidelity is a term used in simulation circles to refer to a relationship between an operational system, environment, and/or item of equipment, and a representation (i.e., a simulation) of that system, environment, or item. While there have been numerous proposals for uses of the term "fidelity" that involved assumptions concerning presumed psychological factors, reference to the physical correspondence between a simulator and the system or equipment simulated has been by far its most frequent use. This traditional definition has led to certain difficulties in simulator design, particularly in the design of training simulators where assumptions have been made that high physical correspondence is necessary to achieve positive transfer of training. However, simulators of very low physical correspondence have been used to train skills that transfer virtually at the 100% level of completeness to operational equipment, and, conversely, some high physical correspondence simulators have been found sorely wanting in terms of the transfer of training they provide. For this reason, attempts to design simulators by specifying the degree of physical correspondence desired have often led to unnecessarily expensive simulators as well as to high physical correspondence simulators that have been poorly suited for conducting some training.

Physical fidelity, in the sense of close physical correspondence, clearly is not an end in itself. It is valuable, and merits investment of the cost that it requires, only to the extent that it contributes to more effective <u>use</u> of the simulator. For simulators used in training, we want characteristics that contribute to effectiveness of the training use that occurs. For simulators used in system design, we want characteristics that contribute to its use in the development of accurate information about system performance. More generally, then, it can be stated that the value of any component of physical fidelity--or any other characteristic of the simulation--results from its contribution to the effectiveness of the system for its intended purpose or purposes.

This general point seems obvious and unarguable. Even so, it may be useful to define a concept that can be used to focus discussion and highlight some implications of the idea. We think that the term "simulator validity" could be useful in this regard. This term refers to the correspondence between the actual results of <u>using</u> the simulator and a set of outcomes that are needed or desired and constitute the objective of its use.

To evaluate the "validity" of a simulator, it is necessary to take into account the purposes for which it is to be used, and to formulate objectives for that use. Typical purposes of simulation include training, performance assessment, personnel and equipment testing, and equipment design. Of course, a particular simulator may be used for several purposes from time to time. Characterization of a simulator as having high or low validity for one purpose or use will not necessarily imply the same degree of validity for another use. Further, specific objectives are required in order to judge whether use of the simulator will have outcomes that match objectives of its use. For example, the general purpose of "training" is insufficient to allow a characterization of the validity of a simulator; the specific objectives intended to be accomplished in training with the simulator must be considered.

To illustrate, simulators consisting of two-dimensional reduced scale paper representations of aircraft cockpits, missile control panels, and other operational equipment have been used very effectively for training various cognitive, discriminative, and procedural tasks associated with the use of such equipment. There is evidence that for these objectives, outcomes of training are quite satisfactory; that is, the paper devices have high validity for the purposes of training cognitive, discriminative and procedural skills. On the other hand, these paper simulators likely have low validity for training or assessment of manipulative or control tasks, since they do not permit these components of performance to be practiced.

Certain difficulties in simulator design can be avoided if fidelity is defined in terms of potential effectiveness for a planned use rather than in terms of physical correspondence. If the simulator is to be used for personnel testing, for example, the performer must be able to discriminate stimuli that cue the performance of specific tasks, and to engage in the performance of those tasks. The extent to which he is able to do so is an indication of the validity of the simulator with respect to a particular testing application. In the case of a simulator to be used for training, the learner must be able to discriminate cues that can be associated with or substituted for cues that elicit specific responses or tasks to be performed in the operational equipment, and to engage in those tasks or in tasks that can be associated with or substituted for them. Validity in a training simulator, then, is limited by the extent to which effective cue and task discriminations, substitutions, and associations are or can be made in training using the simulator. Physical correspondence of stimuli and the responses elicited by them may be important in a simulator to be used for some purposes, but it can be quite unimportant if cue and response variations during training, performance assessment, or equipment design can be accepted through the psychological processes of mediation, and the simulator's outcome objectives can still be achieved.

To enable the validity of a simulator to be determined, a set of outcome specifications is required. For training, outcome specifications consist of the performance objectives that underly the training programs to be conducted in the simulator. For personnel testing, outcome specifications consist of the performance that will be sought in tests that will use the simulator. For use in system design, outcome specifications consist of the kinds of information about system performance, including human performance, that will be assessed in performance trials using the simulator.

The validity of a simulator can be conceived in two ways: potential and actual. If potential validity is high for an intended outcome, that outcome can be fulfilled either fully or in large part, if appropriate programs of use are carried out. Low potential validity indicates that an intended outcome cannot be fulfilled at all or only in small part, regardless of the programs in which the simulator is used. For example, in the case of a simulator to be used for training, its level of potential validity can be viewed as an indication of the amount of training on it that potentially can transfer to the operational system or equipment, i.e., its training effectiveness potential.

Actual validity can only be considered in relation to specific programs of use; in fact, actual validity is a property of a simulation system, including a simulation device used in a specified program of training, testing, or system assessment. The actual validity of a simulator-program system refers to the degree to which specified outcome goals of the simulator match with the outcomes that are achieved when the simulator is used in the way specified in the program.

The traditional definition of fidelity in terms of physical correspondence to the operational system leads to specifications of simulators that ignore the intended uses of simulators; therefore, such specifications are inadequate. Formulation of meaningful outcome specifications involving behavioral and cognitive factors requires analysis of the psychological requirements of tasks to be performed in the simulation situation as well as in the operational environment that is simulated. The need for meaningful outcome specifications implies that procedures or processes to be applied to analyze behavioral and cognitive requirements of human performance are needed in the process of developing specifications for simulator systems.

Technological capabilities needed to conduct such analyses already exist to a considerable extent in the fields of human factors and applied cognitive psychology. They will continue to become stronger as basic research is conducted to analyze further the behavioral and cognitive components of performance and learning in complex task situations. Recent research in cognitive science on processes of problem solving, knowledge structures, and language understanding has significantly advanced our capability for identifying the cognitive skills and knowledge required for intellectual tasks. As research on these topics continues, especially in task domains for which simulators are used for training, assessment, and system design, there will be continued technological advances that can be applied in the formulation of meaningful outcome objectives for simulators.

SIMULATOR TRAINING FOR CONTROL ROOM OPERATORS: LESSONS LEARNED IN FLIGHT SIMULATION

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It has been said that he who does not know history is doomed to repeat it. This observation, while perhaps primarily intended to describe social and political changes, applies to technological changes as well. It certainly applies to the history of uses of simulation in training. He who does not know about others' uses of simulation is likely to repeat many of their mistakes. As a result of the existence of such history and in view of the increasing emphasis upon use of training simulators in the nuclear power industry, it would seem wise to examine the experiences of prior users of simulators in order to identify some of those experiences that might be relevant to the power industry.

Flight training, while not the only area of human endeavor in which simulators have found application, is an area in which there is an extensive, complex, and fairly well-documented history. Consequently, managers responsible for power plant control room operator training might fruitfully look to the experiences of flight training simulator designers and users for lessons to be applied in meeting their own training requirements through use of simulators. Since the reasons most frequently cited to support the acquisition and use of training simulators in aviation have been financial, many of the lessons learned revolve about financial concerns. These lessons provide the point of departure for the present discussion.

The principal lesson to be learned from this past history is that training through simulation, while initially expensive because of the large investment required to purchase a simulator, can reduce long-term operating costs significantly while at the same time increasing operator proficiency. Surprisingly, many managers, while willing to grant the proficiency benefits of simulators, are insensitive to or do not understand these long-term operating cost reduction benefits. Such cost reductions can result from a significantly reduced dependency upon use of operating control rooms to support training, from the reduced possibility of errors or accidents during training that could impact power production, and from more efficient operations after training that result from having more proficient operators. Additional benefits of improved training through simulation include reduced loss of personnel time and enhanced or more positive relationships with the public served and with the population at large. This latter consideration--public relations--is an especially important consideration for those systems in which poorly trained personnel present real or imagined safety risks to themselves and others. One has only to read the daily paper for examples of public concern over the adequacy of operator training in the nuclear power industry, as well as in aviation, the chemical industry, and other work settings.

In spite of such advantages of training through simulation, many managers have expressed reluctance to the incorporation of simulators into their training programs. They often observe that even though simulators may be beneficial, they are too costly to purchase and simply cannot be afforded in their programs. Certainly, it must be recognized that simulators are expensive to purchase, particularly in the power industry where the systems to be simulated are unique, and a one-time developmental cost must be incurred. In addition, there is often a substantial cost for simulator training program development (existing training programs suitable for use with actual control room equipment are seldom if ever equally suitable for use with a simulator of that equipment). The observation that "we can't afford it in our program" also has been made by virtually every aviation training manager who did not already have simulators available for his training. However, detailed examination of all the costs associated with training with and without simulators, particularly the long term costs, has usually produced surprises for those managers. Often, such examination has led to the conclusion that they cannot afford <u>not</u> to have simulators.

There are managers in the power industry who endorse training through simulation, but who urge that efforts be made to minimize the costs associated with simulator purchase and operation. Often they believe that effective training can be obtained using relatively inexpensive "concept" or "generic" devices instead of plant-specific compact, part-task, and full-scope simulators that may be considerably more expensive. In fact, some effective non-plant-specific training can be accomplished with relatively low cost concept and generic devices. However, one of the more important simulation lessons to be learned from past aviation history is that the most successful flight training programs have been the ones that have included use of training devices and simulators that were specific to their aircraft. Flight training programs in which managers have attempted to minimize costs by using concept trainers and generic devices instead have often wound up costing far more in the long run because such programs must include extensive use of the aircraft as a primary training tool. Management decisions that initially appeared wise because they involved minimum capital investment in training equipment, in the long run have often proved to be very costly. In fact, some of the demonstrably most cost effective aviation training programs have involved exclusive use of aircraft-specific simulators even though such devices were expensive to obtain.

It is not necessary that all training be conducted in expensive full-scope simulators. There is no question among specialists in human learning processes that effective training can be conducted in relatively inexpensive devices that permit training only for a portion of the operational tasks. Properly designed compact or part-task trainers can be very useful in many training programs, particularly when training for specific tasks costs less in such devices than in full-scope simulators, or when their use would make more simulator time available for other required purposes. At some point in the course of training, however, it is necessary that all tasks have been trained, and that those tasks be integrated in the manner that is specific to operation of a given power plant. In the more successful and cost effective modern aviation training programs, many individual tasks or related task groups are trained in aircraft-specific part-task simulators. Full-scope simulators are then used to integrate these tasks with others that must be trained entirely in the full-scope simulator.

Another general lesson from the past is that the question of cost justification for simulator procurement is one that should be addressed both in terms of cost avoidance as well as cost savings. With respect to cost savings through simulator training, factors to be considered include the cost of alternative means of training and the need to tie up a power plant for training or to use it inefficiently (e.g., during power-up operations) while training is in progress. With respect to cost avoidance, factors to be considered include lost time due to human error that could be avoided through training on simulators, as well as the direct and indirect equipment, personnel, and public relations costs that could result from such errors. While estimation of the costs associated with these factors may require some judgments to be made, most utilities have data on their training costs, inefficiencies in the use of operational equipment for training, and lost time incidents and accidents that are sufficient to form a basis for estimating costs that can be saved and avoided through more effective training.

Another means of reducing the cost of simulator training that is often tried is to buy time on someone else's simulator. This has sometimes proved to be a cost effective approach in aviation when time is available for purchase on a suitable aircraft-specific simulator. Since there is a relatively high degree of standardization within an aircraft type (e.g., all Boeing 727-200 aircraft are standardized except for minor variations in avionics and instrument displays that reflect the preferences of specific carriers), it is relatively easy for a small airline without simulators to purchase time from a major airline that has simulator time to spare. When such system standardization is lacking, as is generally the case in the nuclear power industry where each control room design is unique, shared use of a simulator is not as appropriate and could even lead to negative transfer of training. The guidelines promulgated by the Federal Aviation Administration concerning the use of aircraft-specific simulators are closely followed in aviation training. Similar, though much less specific, guidelines have been stated by the Nuclear Regulatory Commission and are necessary to assure positive training from simulators in the power industry.

Even in areas in which the NRC has not provided specific guidelines or is permissive, the needs for use of plant- or system-specific compact and full-scope simulators should be recognized by training managers, and training on such devices should be provided. In the future, if control room design becomes more standardized across power plants, purchase of time for training on a suitable simulator owned by another organization that operates similar equipment will be a possible alternative, but such standardization does not exist even within most utilities at the present time.

Another lesson to be considered is that simulator training cost savings will be greater if the simulator is available early and is heavily used. A goal in aviation is to obtain a simulator prior to or concurrent with the delivery of the aircraft simulated so that the initial crews can be trained in the device. This usually means that simulators must be developed concurrently with the development of the aircraft. Further, it is common practice in aviation training to utilize simulators for training for more than two eight-hour shifts per day, six days per week, in order to derive the greatest cost benefits from the smallest number of devices. This frequently means that simulators are used in a wide variety of training programs, e.g., qualification, transition, upgrade, and recurrent training.

The purchase of a control room simulator should not be rejected because of too small a projected need for such training until all possible effective uses of it have been examined carefully. All too often, the mistake is made of underestimating the use that will be made of training simulators, resulting in purchase of too few devices, or possibly none at all. Experience in aviation has shown that simulators prove useful in meeting a wider range of training needs than typically was anticipated by those who had never before used simulators.

Simulation has been characterized by some managers as simply inappropriate to their training needs. These managers express the opinion that the training and management problems of aviation are unique. They maintain that the fact that aviation training has benefited from extensive use of simulation does not necessarily mean that a similar use would be beneficial in meeting training needs in other aras--especially in their own control rooms. Of course, such an opinion may be logically sound in some instances. However, one should not reject the concept of training through simulation because it was "not invented here," or because simulation has not yet been applied as extensively and successfully in the area of power plant operator training as it has been in aviation.

The similarities in training needs across areas of application are sometimes overlooked, and only the differences are highlighted. These similarities include the fact that human learning processes are much the same regardless of the subject matter or skills involved. Complex cognitive and psychomotor skills are required of operators of most complex systems, and these skills usually can be trained more effectively and efficiently in appropriately designed simulators. Further, for complex systems such as aircraft and nuclear power plants, the consequences of human errors can be catastrophic and must be avoided if at all possible. Simulation can provide a means for their avoidance during training for most systems and for their reduced likelihood of occurrence in post training job performance. Rejection of simulator training on the grounds that it is suited only to aviation is often only a reflection of lack of knowledge about training processes and the cost benefits and other advantages to be derived from simulator training in one's own area. The lesson is that acceptance or rejection of simulation should be made only after thorough and competent examination of pertinent cost and training considerations.

Some utilities' managers have observed that their personnel are already well trained through practice in the control room and use of other more traditional training resources and that, therefore, simulators are not required in their plants. Here again, there is a lesson to be learned from aviation. Aviation managers have often found, unfortuntely, that proficiency has not been as high as assumed or as high as it must be when operators are required unexpectedly to cope with off-standard and infrequently occurring situations. In fact, without simulators, it is often impossible even to determine whether pilots are adequately trained to cope with critical situations until the situations occur--and that obviously can be too late. Adequate training to cope with such situations cannot feasibly be provided in most complex systems when training is dependent upon use of operational equipment. Commercial and military aviation became much safer when pilots began to receive emergency procedures training in sophisticated, aircraft-specific simulators, and there is substantial evidence of a causal relationship between these events. Indeed, much of the impetus for development of the current state of the art in aviation simulator training derived from serious concerns about the safety of commercial aviation and the need to provide more comprehensive training in safety related skills. Nevertheless, most managers of pre-simulator aviation training programs were usually firmly convinced that their pilots were being adequately trained in aircraft or in available generic flight training devices. Similar claims concerning the adequacy of existing training have frequently been heard from managers of non-simulator training programs in the electric power industry, such as the programs currently being conducted in nuclear power plant operation. The lessons here from aviation's past are applicable to these training needs.

A final, and perhaps the most important, lesson learned from aviation's past should be considered by all managers responsible for power plant operator training when assessing their needs for purchase and use of training simulators. It is that simulators do not train. They provide a capability or tool for training, but the manner in which that capability is employed is that which yields effective simulator training. It is insufficient to consider only the physical or process simulation of an aircraft, a power plant, or any other complex system. Attention must also be directed to the incorporation of instructional features (some of which, such as fast-time replay and condition store and reset, might even appear inconsistent with faithful simulation of the system) in the simulators, to the design of the interface through which the instructor will function (i.e., the "instructor station"), to the design of programs for efficient use of the device and its instructional features, and to the selection and training of instructional personnel. Unless financial and other available resources will permit extensive attention to be paid to each of these considerations, the potential training benefits of simulation will not be realized. This is perhaps the most significant thing that the past history of simulation tells us that can enhance future uses of simulation by the nuclear power industry.

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16. ABSTRACT (200 words or less) Part I of this report presents technical justification for the use of plant-reference simulators in the licensing and training of nuclear power plant operators and examines alternatives to the use of plant-reference simulators. The technical rationale is based on research on the use of simulators in other industries, psychological learning and testing principles, expert opinion, and user opinion. Strong technical justification exists for requiring plant-reference simulators for operator licensing purposes. Technical justification for the use of plant-reference simulators for operator training is less well grounded empirically, although expert opinion is that plant-reference simulators, when properly used, result in the most effective training. Part II discusses the central considerations in using plant-reference simulators for licensing examination of nuclear power plant operators and for incorporating simulators into nuclear power plant training programs. Recommendations are presented for the administration of simulator examinations in operator licensing that reflect the goal of maximizing both reliability and validity in the examination process. A series of organizational tasks that promote the acceptance, use, and effectiveness of simulator training as part of the onsite training program is delineated.

17. KEY WORDS AND DOCUMENT ANALYSIS

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plant-reference simulator
site-specific simulator
simulator fidelity

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17b. IDENTIFIERS/OPEN-ENDED TERMS

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