Organizational Epidemiology and Energy Facilities

Review of Antecedent Conditions for Human Performance Optimization and Error Prevention

Technical Report

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REPORT SUMMARY

This report reviews background literature and prior research and experience related to causes of human error and prediction of human performance in energy facilities and other settings. Strategic research is recommended to explore the influence of organizational factors and other antecedent conditions on human performance and, thus, on outcomes such as facility productivity and safety.

Background

In energy and other industries, human performance plays a major role in system performance, and human error contributes to most costly accidents and mishaps. The most frequently used approach to study human error and reduce its impacts is retrospective (review of an accident leads to identification of corrective action[s] intended to prevent repetition of the accident). Although the retrospective approach has yielded significant benefits, the ability to predict human performance could support more efficient allocation of resources towards error reduction, safety, and productivity enhancement.

Objectives

To review background literature and prior research related to causes of human error, prediction of human performance, and analysis of human error data within the context of facility performance (with the aim of identifying approaches for improving both human and facility performance in energy industry settings).

Approach

The project team identified prior work on predicting human error and performance deficiencies in industrial settings through literature searches, conferences, and interaction with researchers and energy industry personnel. The team placed an emphasis on identifying potential antecedent conditions and trends that could predict changes in human performance, as well as on locating related prior efforts to analyze human error data within the context of facility performance. Recommendations were developed for future strategic research.

Results

Several hundred technical articles, books, and presentations were reviewed; a substantial annotated bibliography is included in the appendices. The study found that most empirical research on human errors and performance deficiencies in industrial settings relies on review of accidents, mishaps, and incidents through error reports alone. Only infrequently has research also considered measures of the ongoing workplace context where human performance occurs. This report recommends an *organizational epidemiology* approach, which combines data relating to human error and human performance with contextual information that could reveal antecedent conditions for human performance changes. Ideally, corrective and/or preventive actions could

be implemented based on the appearance of such antecedent conditions—before safety and productivity costs have mounted. Conversely, identifying positive antecedent conditions (those associated with good performance) could contribute to improved resource allocation and increased productivity. It also could provide early validation of preventive or corrective actions. Methods and tools that enable prospective or proactive human performance intervention, thus, could prove extremely valuable in the energy industry and other sectors.

EPRI Perspective

This review was initiated as a conceptual foundation for and lead-in to the "Human Performance Management: Database and Analysis" (HPM) project under the Strategic Human Performance Program. The HPM project seeks to improve understanding of how worker-, workplace-, management-, and organization-centered factors affect human and facility performance. Since project inception, an emphasis has been placed on linking data regarding performance with information on workplace conditions to explore possible relationships between events or accidents and organizational attributes. This review found that the study of proposed data linkages may be termed *organizational epidemiology*, and it recommended research to explore the predictive usefulness of measures that reflect the influence of organizational factors and other antecedent conditions on human performance.

Another strategic study performed under the HPM project, "Predictive Validity of Leading Indicators of Human Performance," has taken an initial look at this type of approach (1004670) based on EPRI nuclear work to develop leading indicators of organizational health for nuclear power plants (TR-107315, 1000647, 1003033; because this work was funded by the Nuclear sector, these reports are available only to funders of that sector). In continuing HPM research, analytical and statistical techniques are being applied to uncover hidden patterns that represent antecedent conditions for human performance problems (see 1004669, scheduled to be published by late 2002). Such analytical foresight and the attendant predictive capability could help improve human performance as well as the safety and productivity of energy facilities.

Keywords

Human error
Accidents
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Data analysis
Organizational epidemiology
Leading indicators

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1
INTRODUCTION

Human performance is a critical determinant of safety and economic performance in many industries, including the energy industry. For example, it is often estimated that a majority of significant events (accidents or mishaps) in commercial nuclear power plants and other industrial facilities—perhaps as high as 70-80%—involve human error or inappropriate action as a critical element (e.g., Ayres *et al*., 1993; Muschara, 1997). In addition to contributing to significant events, human error also plays a frequent role in exacerbating the severity of consequences (Fujimoto, 1994; Heyes, 1995). Successful reduction of human error problems yields clear benefits with respect to both safety and cost (e.g., Lanoie & Trottier, 1998; Smith & Larson, 1991).

The most frequently used approach to study human error and reduce its impacts is retrospective, i.e., review of an accident leads to identification of corrective action(s) intended to prevent repetition of the accident. Corrective action efforts are an important part of safety improvement. Accidents are expensive lessons, but the costs are much greater if the lessons are not heeded. By sharing the lessons of an accident beyond the specific site where it occurred, the cost is offset somewhat by the extended benefits (at least from a societal perspective, if not on the balance sheet of an individual company).

In regulated high-risk industries such as the energy industry, particularly commercial nuclear power generation, the potential high cost of events—including the remote but real possibility of catastrophic outcome—motivates prospective efforts, i.e., identification of antecedent conditions associated with human error and performance problems. Ideally, corrective and/or preventive actions could be implemented based on the appearance of such antecedent conditions—before safety and productivity costs have mounted. Conversely, identification of positive antecedent conditions (those associated with good performance) could contribute to improved resource allocation and increased productivity. It also could provide early validation of preventive or corrective actions. Methods and tools that enable prospective or proactive human performance intervention thus could prove extremely valuable in the energy industry and other sectors.

Numerous tools for human performance improvement based on management of organizational factors have been proposed and applied in industry settings (see review in EPRI, 2001d); selection of site- or situation-specific tools would benefit from identification of antecedent conditions.

Research Context

The “Human Performance Management: Database and Analysis” (HPM) project, a major element of EPRI’s Strategic Human Performance Program, seeks to improve understanding of how aspects of worker-, workplace-, management-, and organization-centered factors affect human and facility performance. The overall strategic program is providing tools, capabilities, and services to optimize human productivity and reliability in specific workplace environments, as well as to anticipate and address factors with adverse impacts on human performance and on the productivity, reliability, and safety of energy and other facilities.

This literature and background review was initiated as a lead-in to the HPM project. It was planned as an effort to survey relevant technical human performance literature and state-of-the-art applied human performance data collection, handling, and analysis practices for and in industry and government. An exhaustive or comprehensive survey of possibly relevant technical literature would be a monumental task; furthermore, there would be extensive overlap with other reviews and compendiums, including general works such as Boff *et al*. (1986) or Salvendy (1997) and reviews on human error and accidents such as Hoyos & Zimolong (1988) and Reason (1997).

The review's apparent emphasis on literature related to nuclear power plant operation reflects the leading role of that sector in pursuing study of human errors and human performance. It appears, however, that the lessons learned in the nuclear sector may be generalized to other aspects of the energy industry, including non-nuclear electricity generation and power transmission and distribution. Findings that have been reported from analyses of human error contributions in fossil generation and switching incidents, for example, suggest that similar types of errors and contributing factors pervade work settings in general.

The literature and experience review described in this report is intended in large measure as support for empirical research conducted under the strategic HPM project. The central study of the HPM project seeks to apply what may be called "organizational epidemiology" (Rosenthal, in Hale *et al*., 1997). The concept involves linkage of data regarding human and facility performance with information on workplace conditions in order to explore possible relationships between corporate performance measures, such as events or accidents, and organizational attributes. The study takes a broad perspective on the types of antecedent conditions that could influence both human and facility performance. The study and its results will be described in a separate EPRI report scheduled to be published in 2002; an interim report, *Organizational Epidemiology: Analytical Approaches for Predicting Human and Energy Facility Performance* (EPRI, 2002), is available on the Strategic Human Performance Program website (log on at http://www.epri.com/targetContent.asp?program=255856&value=02TSST501 and click on "Human Performance Program"). Another study performed under the strategic HPM project, the "Predictive Validity of Leading Indicators of Human Performance" (PV) study, has taken an initial look at this type of approach (EPRI, 2001b).

Interim findings from this literature and background review have been briefly summarized in several conference presentations (Murray *et al*., 1999; Gross *et al*., 2000; Gross *et al*., 2001).

In addition to providing a conceptual foundation for and lead-in to the strategic HPM project, the review was a deliverable for the EPRI (Nuclear/Strategic) Human Performance Initiative. This initiative, completed in 2001 as a technical innovation under EPRI's Business Sustainability Performance Indices, has helped support the development of a structured approach for understanding and managing the organizational factors that influence human performance so as to enhance the human contribution to overall facility performance, to identify potential human errors before they become a problem, and to develop appropriate corrective action plans to preclude such errors in the future.

Report Organization

Section 2 of this report characterizes human error and describes how discovery of the factors contributing to human error, i.e., the antecedent conditions, may enable development of proactive human performance improvement measures.

Section 3 contrasts deductive and inductive (or empirical) approaches for studying human error in the context of EPRI's strategic HPM project. The next three sections describe critical elements for empirical analysis of human error. First, detailed error data need to be collected and organized (Section 4). Second, extensive related data reflecting background conditions must be identified or gathered (Section 5). Finally, analytical tools for discovering patterns and predictive relationships need to be applied (Section 6).

Section 7 describes candidate methods for use in analyzing error and background data. Section 8 identifies types of data and human and facility performance measures that might be available for energy facilities. It also describes the PV study and lessons learned (EPRI 2001b) in some detail. Section 9 summarizes key findings from the literature and experience review and the PV study, providing guidance for subsequent research under the strategic HPM project and by others.

The literature review is described and presented in Appendices A, B, and C. To help users in identifying work of potential interest from the considerable volume of literature that was reviewed, each reference was assigned to one or more categories according to subject matter. In addition, short descriptions or summaries were prepared for each reference. Appendix B organizes the references by category to simplify the search process; under each category heading, references are listed by date. Appendix C contains the annotated bibliography itself, with references listed in standard alphabetical order. Category labels assigned to each reference are also provided.

2
HUMAN ERROR—CAUSES AND ANTECEDENTS

Throughout most of the 20th century, efforts have been made to improve human performance and reduce human error, from the scientific management work of Frederick Taylor through the birth of human factors as a discipline in World War II and the subsequent application of increasingly powerful analytical tools.

Much has been written about human error. Numerous reviews are available (e.g., Miller & Swain, 1987; Park, 1997; Reason, 1990, 1997), and a variety of cognitive models have been developed for error generation. This paper does not pretend to present an exhaustive review of the literature on human error; the materials reviewed for this project, extensive as they are (over 300 books, papers, and articles), cannot be more than a small exploratory sample, and no attempt has been made to summarize completely the contents of the materials reviewed. Rather, this report discusses tentative conclusions reached (based on the literature reviewed) regarding research directions for uncovering antecedent conditions.

Human Error

The study of human error has been filled with controversy. Summing up a conference on human error that involved a veritable who's who of major researchers in the field, Senders and Moray (1991) found that "almost the only point of agreement at the conference was that it is fruitless to look to classifications based on neurological events." A recent review of human error concluded that “there now appears to be as many human error models as there are people interested in the topic” (Wiegmann *et al*., 2000).

Indeed, the term *human error* is itself controversial. The term, unfortunately, implies fault and invites blame, but many errors are completely blameless with respect to the person who acted improperly. Hollnagel (1993) prefers the label *erroneous action*: "any action which fails to produce the expected result and which therefore leads to an unwanted consequence." Straeter (2000), on the other hand, discusses errors of commission as "a result of mismatch between situational circumstances and internal representation of the world." The general term *human error* will be used in this review for the sake of convenience, since it is the most common term in the field, but public pronouncements and workplace safety programs would do well to adopt more neutral language to refer to situations in which human action or inaction is judged to be less than adequate.

Human error is sometimes distinguished from deliberate inappropriate action or inaction. Maurino *et al*. (1997; see also Reason, 1990, 1998) divide unsafe acts into errors (including slips and mistakes) and violations (willful misconduct). Others retain the distinction between unintentional and intentional errors: e.g., on the one hand errors of skill, rule, and knowledge; and on the other hand errors of judgment or attitude (Lehto, 1991; Ayres *et al*., 1993; Gertman *et al*., 1994).

For this project, *human error* is understood to include both unintentional and intentional errors of commission or omission, while it is recognized that categorizing errors by type or circumstance could be useful for understanding, prediction, and prevention. For example, in an examination of a large number of performance-shaping, error-causing, and error-triggering factors, Yoshino & Inoue (1992) found that experts in nuclear power safety felt that errors in judgment and decision-making had the greatest influence on plant safety. Similarly, work in other domains suggests that violations or errors of judgment/attitude are the most common human contributors to accidents, as well as the most difficult to address with training efforts (see Figure 2-1).

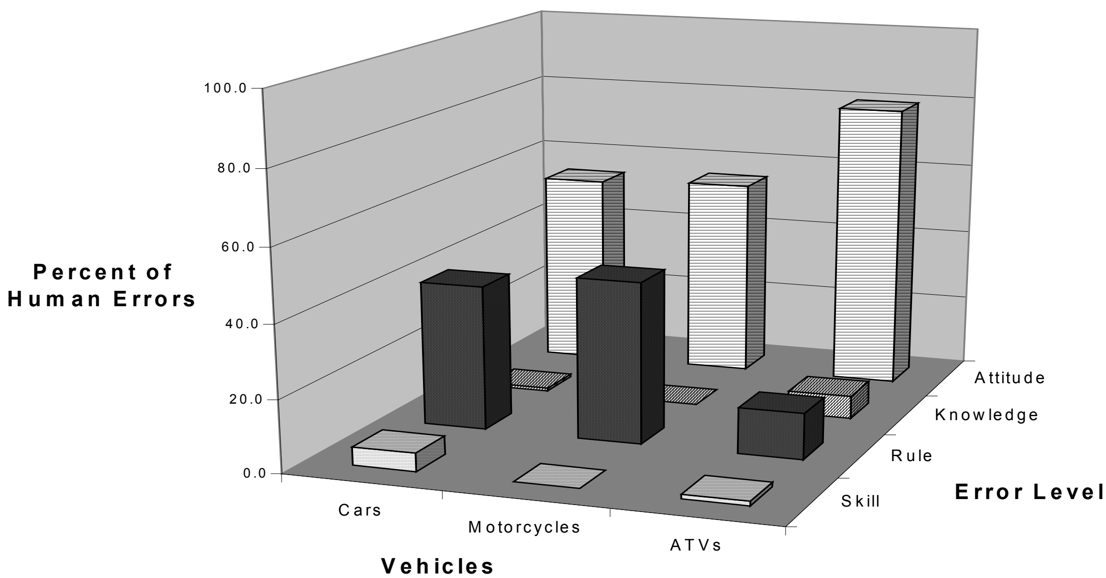

Figure 2-1
Types of Human Errors as Contributing Factors in Motor Vehicle Accidents (source: Ayres *et al*., 1993)

Most researchers agree that human error is ubiquitous, and that it can be reduced but not eliminated (e.g., Reason, 1997); a zero-error goal is unrealistic (Reason, 2000b). Psychologists who study human performance in tasks such as problem solving and decision-making conclude that human cognition is fraught with limitations and biases that make error inevitable, especially in complex situations (e.g., Dorner, 1996). Although some organizations use the goal of zero human errors as a target, it is more common and certainly more realistic in most situations to try to reduce (not eliminate) the frequency of human errors and to control the consequences of errors (e.g., through defense in depth so individual errors will not lead to serious accidents).

In order to find ways to reduce error frequency in the workplace and control the associated consequences, it is important to identify antecedent conditions for human errors. Strictly speaking, it is not necessary to identify *causes* of human error, nor even the facilitating factors that allow errors to occur (although a knowledge of both causes and facilitators would be very helpful, and this approach receives considerable research attention). Rather, considerable safety gains should be possible if *antecedent conditions* can be discovered, allowing managers and supervisors to predict general error trends and spot trouble in advance, even if the causal links are not understood.

Antecedents

It is important to begin with an understanding of what is meant by an *antecedent condition for human error*. Some confusion could arise by association with the venerable A-B-C (antecedent-behavior-consequence) model of human behavior, widely used as a basis for behavioral safety programs in industry (see, e.g., Zohar, 2002). In that formulation, based on operant learning principles, an antecedent elicits a behavioral act; the consequence that follows affects the likelihood that the antecedent will elicit the same behavioral act in the future. Thus, if a person takes a short nap (behavior) when the supervisor goes on an errand (antecedent), and if the person is caught and reprimanded (consequence), then it is less likely the person will take a nap at the next such opportunity; conversely, if the nap goes undetected and the person enjoys relaxing, he/she will be more likely to take a nap at the next such opportunity. The initial connection between the antecedent and the behavioral act is strengthened or weakened by the nature of the consequence (e.g., by positive reinforcers or by punishers). In more cognitive terms, the antecedent functions as a signal or trigger for likely (reinforced) or unlikely (punished) behavior. The A-B-C model has proven useful for designing safety intervention programs.

In the current HPM project, however, *antecedent conditions* are circumstances that are *causally* related to subsequent performance changes. Because the project emphasizes negative performance changes resulting from human error, the search for antecedent conditions concentrates on antecedent conditions for human error (ACHEs). It is just as reasonable, however, to try to find antecedents for improvements or, more generally, antecedents for human performance changes.

In order to be useful for predicting future performance, antecedent conditions need to be causally related to the performance; otherwise there would be no reason to believe that the antecedent conditions would have predictive value. It is important to note that the causal relation can take several forms. An antecedent condition can *cause* a human performance change, either directly or indirectly, as follows:

- **Direct cause**: e.g., if hot weather caused people to have mishaps.
- **Indirect cause**: e.g., if hot weather caused high absenteeism, which in turn led to mishaps.

Another possibility is that an antecedent condition can reflect or be affected by some factor that also causes a human performance change, either directly or indirectly. Examples are presented below:

- **Direct reflective relationship**: e.g., if hot weather caused both a quick rise in minor injuries and a later increase in mishaps, then a rise in minor injuries could be an antecedent condition that would predict an increase in mishaps even though it does not cause the increase.
- **Indirect reflective relationship**: e.g., a rise in minor injuries could reflect hot weather, which may also give rise to errors in maintenance that later cause plant performance problems.

Thus, the search for ACHEs includes but is not limited to the search for causes of human performance problems.

3
APPROACHES TO STUDYING HUMAN ERROR

In order to find antecedent conditions of human performance changes or human error, there are two general approaches: deductive and inductive. Deduction involves reasoning from principles to specific conclusions; induction involves generalization from data to general rules. The contrast between these approaches can be used to characterize the difference between much of the previous work on error prevention, on the one hand, and work now being pursued by EPRI's Strategic Human Performance Program.

Deductive Approach

Deduction makes use of human intuition and insight to develop models of human error and organizational behavior. As a prime example, the search for *leading indicators* of human performance has involved thoughtful review of both research literature and accident data. Work for the U.S. Nuclear Regulatory Commission (NRC) has produced proposed leading indicators for nuclear power plant safety based on experience in other industries; proposed indicators include significant incidents, reportable incidents, precursor incidents, equipment-forced downtime, safety system unavailability, and unrelated contained releases (Connelly *et al*., 1990; Van Hemel *et al*., 1991; see also American Society for Quality, 1999).

Reason (1991, cited in Reason, 1997) proposed five clusters of safety process measures, grouped as safety-specific, management, technical, procedural, and training factors.

More recently, in work funded by the EPRI Nuclear Human Performance Techology Program, review of available models of human performance led to the identification of seven "recurrent themes" that could form the basis for proposing leading indicators of human performance (EPRI, 1999b; EPRI, 2000b; Wreathall & Jones, 2000). The seven themes represent a high-level or very general synthesis of cultural or organizational factors. Through a process of deduction and discussion, the themes could be tied to industry-specific issues and eventually to potential indicators that would reflect conditions at the site or facility relevant to the corresponding themes. Since the themes were intended to represent factors that are widely believed to affect human performance in work settings, it was hoped that related indicators could serve as leading indicators, giving advance notice of human performance changes (see Figure 3-1).

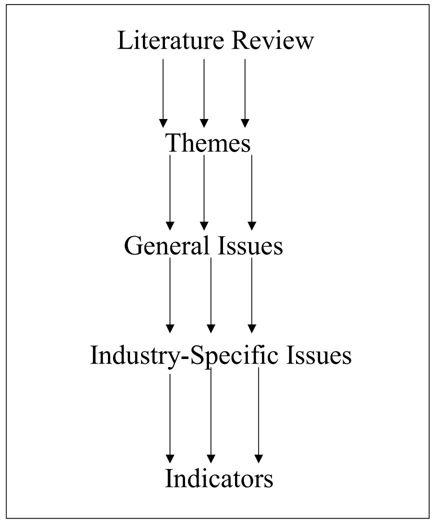

Figure 3-1
Top-Down (Deductive) Reasoning: the Leading Indicators Project

In a strategic project, an empirical exploration has been completed of the predictive validity of the leading indicators methodology (EPRI, 2001b). Results provided support for the premise that such indicators ultimately might help predict facility performance outcomes and guide human performance interventions. Practical lessons regarding research methodology issues are discussed in Section 8.

Inductive Approach

At the opposite end of the spectrum, a purely inductive approach would start with data on human performance and the workplace context, and atheoretical analyses would be used to look for patterns or relationships. In principle, given enough data about the background or context in a workplace—along with information about observed human errors—it should be possible to discover predictive relationships (if any exist) between background antecedents and the errors.

In practice, a purely inductive approach does not make sense for this issue; some initial decisions need to be made about the data to be collected, based in part on intuition or convenience. The models and findings of the deductive approach can be used here to suggest potentially interesting measures. Alternating the complementary processes of induction and deduction—observations lead to generalizations which lead to hypotheses to be tested with further observations—is a normal feature of experimental sciences.

Most attempts to identify potential ACHEs involve (or begin with) deduction. For example, if any accidents seem to have occurred when workers were tired, it makes sense to suggest that the presence of work rules that lead to fatigue might be a predictor or antecedent condition for human performance problems (logical deduction). Thus, a combined approach—reasoning from observations to hypothesized principles (induction) and then back to potential specific indicators (deduction)—is useful for suggesting potential antecedent conditions.

The distinguishing feature of a strongly inductive approach to human error precursors (or an inductive phase of investigation) is the effort to collect a wide range of measures about context or background (and thus about possible antecedent conditions) without second-guessing the nature of any relationships that may show up. Rosenthal (in Hale *et al*., 1997) proposed the pursuit of *organizational epidemiology*, linking databases to explore possible relationships between accidents and the attributes of organizations and regulatory systems in the chemical industry. The hope is to find emergent and perhaps unanticipated patterns of relationships. Instead of starting from a proposed causal relation then seeking confirmation, the inductive approach would discover a consistent relationship between conditions and performance and, thus, invite speculation or research to understand the causal basis.

In order to conduct such organizational epidemiology in the energy industry, three components are needed, as discussed in this review. First, detailed error data need to be collected and organized (Section 4). Second, extensive related data reflecting background conditions must be identified or gathered (Section 5). Finally, analytical tools for discovering patterns and predictive relationships need to be applied (Section 6).

4
DATA REGARDING POTENTIAL MEASURES OF HUMAN PERFORMANCE

The first major hurdle for an inductive or empirical approach to human error analysis in complex organizations is selecting and obtaining data. As an example, one research effort reviewed 35 different categories of workload measures that might be used to study air traffic control (David, 1999). The number of variables that might be studied in a large work setting such as an energy facility is intractable. Even in the restricted environment of a control room, many types of measures of work conditions, operator conditions, and human and system performance have been considered, such as in the ongoing research program at the Halden Reactor Project (e.g., Haugset, 1997).

Data Availability

From a practical standpoint, it would be ideal to find useful measures among the data streams that are collected on a routine basis (as opposed to requiring new variables to be systematically observed). This would allow researchers to study the predictive value of the various measures using historical (archived) data; it would also allow organizations to make human performance predictions without additional and possibly cost-prohibitive data collection efforts. Discovery of predictive relationships requires considerable historical data. Thus, finding predictive value in the data that have been collected for years at energy facilities would help companies obtain practical results more quickly and more economically than if new data collection procedures had to be instituted.

Although data-intensive organizations such as nuclear power plants already collect a staggering amount of data, there is no assurance that they collect the right data for examination of potential antecedent conditions for human performance and safety. For example, it is easy to imagine that critical aspects of human performance may be influenced by workers' nutrition (Wyon, 1998) or sleep problems (Young, undated), not to mention their morale and safety attitudes; it is possible that none of those factors are adequately reflected in the streams of data currently being collected at most power plants.

Data Utility

An empirical inductive approach to studying context-behavior relationships needs to cast a rather broad net for data, but some tentative guidelines also need to be adopted for what is most likely to be useful. Rather than relying too heavily on intuition or educated guesswork, it is appropriate to consider research on factors that influence human performance. Indeed, that has been a major goal throughout the literature review conducted for this project: learning from past efforts to identify worker-, workplace-, management-, and organization-centered factors that influence human and facility performance and to use these factors for predicting future performance.

Fortunately, there are valuable published reviews to draw upon. Numerous reports have noted that the term *organizational factors* does not have a precise meaning for safety efforts (e.g., Rollenhagen 1999; Willpert & Miller, 1999). Rollenhagen proposed a generic model of technological systems such as nuclear power plants; his model considers the activities of the people involved, the various resources they need (e.g., information, personnel, time, budgets), and the hardware or physical plant, as well as possible external influences; these categories can form the basis for identifying issues to be raised in questionnaires or interviews. Willpert and Miller claimed to find approximately 160 different factors proposed in 13 organizational factor models that they reviewed; a team of system safety experts reduced these to just over 60 factors, grouped in seven categories:

- Interorganizational relations
- Vision, goals and strategies
- Supervision and control
- Operation management
- Resource allocation
- Performance
- Technology

In 1998, the Organisation for Economic Co-operation and Development sponsored a workshop to discuss organizational factors related to nuclear power plant safety, with participants drawn from worldwide regulatory bodies, energy companies, and research institutes. The report based on that workshop (Committee on the Safety of Nuclear Installations, 2000, Vol. 1) describes a consensus of participants on 12 major factors regarded as important for safety:

- External influences (from outside the boundary of an organization)
- Goals and strategies
- Management functions and overview
- Resource allocation
- Human resources management
- Training
- Coordination of work
- Organizational knowledge
- Proceduralization
- Organizational culture
- Organizational learning
- Communication

The workshop report provides definitions and "aspects" for each factor; for example, *coordination of work* includes the following:

- Organization of interrelated work activities
- Identification of roles and responsibilities and delegation of responsibilities
- Shift work, shift turnover, and team composition
- Inter- and intra-organizational communication and coordination
- Prioritization, planning, and scheduling of work activities
- Planning of work to allow an appropriate workload distribution
- Logistics, assistance, and support
- Management of personal workload and workflow
- Traceability of work activities
- Coordination of contractors with licensee employees

The report goes on to note that a variety of techniques are "commonly believed to be useful in gathering data about organisational factors," including the following:

- Behavioral observations
- Checklists
- Structured interviews
- Simulations
- Rating scales
- Document analyses
- Event reviews
- Surveys and questionnaires
- Focus groups
- Trend analyses of performance data

Comparison of the 12 major safety factors (and their many aspects) with the list of common research techniques reveals a crucial problem for the strategic HPM project. Most of the research techniques, with the exception of some types of performance data, would be unusual to find routinely in energy industry or other organizational settings. On the other hand, many of the items listed as aspects of the major safety factors have no clear counterparts in routinely archived facility data.

The same observation could be made with respect to the characteristics that are said to be central to successful operation of complex organizations. High-reliability organizations (according to the HRO group, e.g., Roberts & Grabowski, 1994; Grabowski & Roberts, 1997) are said to display four characteristics (Committee on the Safety of Nuclear Installations, 2000, Vol. 1):

- Agreement among members regarding goals and objectives
- Redundant decision channels and controls
- Comprehensive training programs
- Flexible organizational structure

With the possible exception of training, these characteristics probably need to be assessed through a variety of interviews, questionnaires, and organization observations. It is unlikely that direct measures of, e.g., the flexibility of the organizational structure, are routinely collected by typical organizations. The possibility exists, however, that routine data may provide surrogate measures—ones that indirectly reflect the influence of these or other important characteristics. It is not essential to understand connections between measures and underlying factors, although theory (or models or hunches) could lead to exploring otherwise nonobvious measures.

For example, variables that seem likely to tap aspects of safety culture and organizational climate are worth including, along with various proposed leading indicators. One of the most fruitful suggestions for capturing the workplace context-behavior relationship is that of a *safety culture* or *climate* (e.g., Zohar, 1980; EPRI, 2001a). Westrum (1999) proposes that a strong safety culture in an organization has the following components: strong emphasis on safety, a high degree of cooperation and cohesiveness, encouragement of effective and free-flowing communication, clear sense of its own safety condition, and a learning orientation with regard to its mistakes. Westrum offers ideas for how the strength of the safety culture might be measured in an organization; e.g., the prominence of safety among performance indicators would reflect the safety emphasis, and a general feeling among personnel that management listens to the workers' concerns would reflect cooperation and cohesiveness. Similar suggestions have been offered by Wert (1987, 2001).

Several researchers have reported evidence of a positive relationship between safety climate and actual or perceived workplace safety. Diaz and Cabrera (1997) claimed to find a relationship between safety climate and expert-judged safety when comparing three companies working at an airport. Friedlander and Evans (1997) reported that human error scores were correlated with corresponding corporate culture scores in an electric utility. Gibbs and Adams (1999) found that inter-site differences in safety practices in the chemotherapy drug industry were attributable to workplace culture factors. Helmreich and Merritt (1998) brought together evidence for the importance of various cultural influences on workplace safety and performance, including national culture, professional culture, and organizational culture. A path analysis of conditions at the FAA Logistics Center found that organizational politics, goal congruence, and supervisor fairness contributed to perceived management support for safety, which in turn determined perceived safety conditions (Thompson *et al*., 1998).

There is also overwhelming evidence that human performance is affected by stress and workload, giving rise to many attempts to predict and assess stress and workload as a function of task, setting, and other factors. Organizational factors can increase workload, leading to stress and thus impaired task performance (e.g., Xiao *et al*., 1998). Various types of stress have been implicated in accidents (e.g., McCallum *et al*., 1996). Stress management techniques have been introduced with power plant operators to reduce problems with attention, memory, and team communication (Desaulniers, 1997). Research on human performance and errors suggests that performance decrements are often associated with particular times of day, fatigue and distraction, and/or work overload or stress (e.g., Koval & Floyd, 1998; Weikert & Johansson, 1999); workplace measures that tap such factors should be sought.

In a study of marine accidents, Moore (1993) determined that accident reports from the U.S. Coast Guard were not sufficiently detailed “to determine whether human errors are the result of errors rooted in organizations or the result of individuals acting upon their own initiative.” Based on extensive study of several major marine accidents involving use of influence diagrams to try to model the apparent causal factors in the chains of events leading up to the accidents, Moore proposed an Overall Human Error Safety Index based on five component indexes:

- **Human error safety index**: "quantitative measurement of human error conditional upon a set of organizational errors, human factors, system and environment factors for a specified EDA [event, decision, and action]."
- **Organizational error index**: impact of top-level management upon mid- and operator-level management error effects.
- **Human factor index**: product of a stress index and a routineness index.
- **System index**: judgments as to impact of system factors on overall safety index.
- **Environmental index**: product of external and internal operating condition impairment indices.

Moore’s general conclusion—that operational safety depends on a wide variety of organizational, environmental, task, and worker factors – is consistent with the findings of other researchers and reviewers. Wreathall *et al*. (1991) summarize this state of affairs in the “onion model” of human performance influence factors, with the worker at the center of rings of influence from the team and work environment, the surrounding organizational and corporate factors, the plant and site conditions, and the outside public and regulatory environment. Such factors have been codified as *performance-shaping factors* for probabilistic risk assessment in the nuclear power industry (e.g., Swain & Guttman, 1983; Lin *et al*., 1992; Gertman *et al*., 1994; Mojeni & Orvis, 1994; Cooper *et al*., 1996; Park & Jung, 1996; Thompson *et al*., 1997; see Cooper *et al*., 1996, for a discussion of errors and performance-shaping factors used as a basis for the development of the ATHEANA human error analysis process).

Another good starting point for considering candidate ACHEs would be one of the numerous taxonomies or checklists that have been developed for identifying types of human errors or human contributions to industrial accidents; these lists have been developed to encompass a broad range of factors that incident investigators identify. Such lists are available from the NRC (e.g., Eckenrode, undated), the Institute of Nuclear Power Operators (INPO; e.g., Harrison, 1993), the Maintenance Error Decision Aid for aircraft maintenance (MEDA; e.g., Hibit & Marx, 1994), the International Civil Airplane Organization (ICAO; e.g., ICAO, 1993), and others.

The selection of appropriate and useful variables to include will likely be an iterative process. Based on preliminary analyses, if some factors seem to have no predictive value, they may be given lower priority for future data collection. On the other hand, ruling out variables on the basis of intuition, past research, or failure to find an interesting pattern may compromise the chances of finding new and nonintuitive patterns when a larger data set becomes available.

5
HUMAN ERROR DATA COLLECTION

Issues associated with three potential sources of data on human error and human performance are categorized below.

Simulators and Laboratory Studies

One important barrier to understanding human error in complex work systems is the difficulty of getting data. Behavioral scientists yearn for control in test situations in order to eliminate extraneous influences and to permit systematic manipulation of parameters, but the complexities of an occupation such as power plant control room operation are not readily reproduced in the lab as easily as, for example, motor vehicle operation. Performance of discrete tasks has been studied in laboratory simulations such as teleoperation (Endsley *et al*., 1997); data from simulators are generally used for estimating human error probabilities (Dhillon, 1986) in conjunction with expert judgment (Auflick *et al*., 1997), despite methodological problems (e.g., Apostolakis *et al*., 1988).

The extensive research using simulators to study human error has played a major role in quantitative prediction of human error, contributing estimates of human error probabilities for use in human reliability analysis as a part of probabilistic risk analyses (e.g., Clarke & Wimpenny, 1995; Swain & Guttman, 1983). Simulator data are an important source for human error probability estimates, as are workplace error data, laboratory experiments, and expert judgment (Park, 1997; Kirwan *et al*., 1997); extensive electric power control room simulator research continues at centers such as the Halden Man-Machine Laboratory (HAMMLAB).

There are problems with simulator research, however (for a discussion see, e.g., Blackman & Byers, 1998; Parry 1994). Simulator studies do not offer insight into the larger workplace context in which errors take place. In addition, a limited amount of work can be done with simulators—limited in part because the time needed for extended testing can be prohibitive for the facility personnel. Ultimately, the workplace itself, with its real-world complexity, is the most appropriate source of data.

Incident data in some form is needed in order to validate any models or predictions related to human error or to human performance improvement. For example, doubts have been raised about the value of various proactive human factors efforts in the nuclear industry, such as detailed control room design reviews (Feher, 1997; Van Cott, 1997). Also, numerous analysts have suggested that error prediction techniques that have proved very useful for equipment and plant systems may be much more problematic for human error (e.g., Embrey, 1992; Hollnagel, 1993), restricting purely proactive efforts to qualitative modeling (Stanton & Baber, 1996).

Unfortunately, there are barriers to studying human error in highly complex systems such as commercial energy facilities. Most psychologists and other academically grounded error researchers lack detailed understanding of plant operation (Lee, 1996), whereas analysts within industry tend not to have extensive backgrounds in the tools and concerns of the behavioral sciences. Intense ongoing collaborative projects that bring behavioral researchers into industry contexts for applied research play an important role in bridging this gap; the Center for Human Performance and Risk Analysis at the University of Wisconsin, Madison (http://www.engr.wisc.edu/centers/chpra/), is one example of an attempt to bring researchers and practitioners together, such as through conferences.

Incident Reports

The most obvious source for information about human error in the workplace is incident data. The term *incident* is used here to cover a wide spectrum, from major accidents and events at one end, through minor mishaps to near misses, with inconsequential errors at the other extreme. Catastrophic accidents need to be studied in great detail because of their severe consequences, but (fortunately) they are too rare to permit systematic study of the causes and likelihood of human error. Accident frequency, of course, is at least partly a function of *exposure*, or how often a given activity takes place; it is not surprising that there are more fatal accidents in the trucking industry than in the nuclear power industry, given that far more annual person-hours are spent working in the former than in the latter.

Sets of accident reports have been collected for many industries (as well as for consumer product usage, recreation, motor vehicle operation, and other non-occupational settings). Examples include aviation (Nagel, 1988), especially the Aviation Safety Reporting System (ASRS), a voluntary reporting system (e.g., Quinn & Walter, 1997); aircraft maintenance (Wenner & Drury, 1996); marine operations (Bea & Moore, 1994); and manufacturing (Nakajo, 1993). For U.S. nuclear power plants, extensive collections are maintained by INPO, the NRC, the DOE, and others (e.g., Trager, 1997); nuclear safety reports are also available from other countries (e.g., Fujimoto, 1996; Legrand, 1996).

Review of incident reports can provide insight into commonly attributed causes as well as the apparent success of various safety interventions, such as with regard to errors involving selection of the wrong unit or train in a nuclear power plant (EPRI, 1994). Data regarding injuries at a number of energy companies are being studied in an ongoing EPRI project (EPRI, 1999a, 2000a). Various analytical techniques have been applied to such data sets, as discussed later.

Even accident reports, however, have limitations for studying human error. Thompson *et al*. (1998) suggest four problems with accident data:

- Accidents (even minor accidents) are rare within any given workplace or setting.
- Accident situations are not always under the control of the people involved.
- Reporting detail is inconsistent.
- There is usually a bias towards reporting the more serious accidents.

Tamuz (1994) suggests that organizations have trouble learning from accidents because such events are important (thus there is fear of corporate liability and of individual punishment) and are often complex (thus hard to understand). For reasons such as those suggested by Thompson *et al*. and Tamuz, accidents alone typically do not permit organizations to balance safety and productivity needs (i.e., navigating the safety space, according to Reason [1997]).

Near-Miss Reports

There is also considerable interest in collecting information on near misses or inconsequential errors (e.g., Van der Schaaf, 1999). Near misses are seen as inexpensive opportunities to learn, allowing management to catch potential safety problems before they lead to major problems (Bier & Yi, 1994; Perin, 1997). Errors are viewed as not only inevitable but actually desirable as an indicator of where one is in a "safety space" that extends from over-protection to under-protection (Reason, 1997; Wildavsky, 1988).

Near misses are assumed to be much more frequent than accidents, and they often involve a single error rather than a chain of fortuitously (or unfortuitously) aligned problems. They have been used to study factors such as situational awareness in aircraft cockpit operations (Jentsch, 1999), workforce segmentation for electrical safety in chemical processing (Capelli-Schellpfeffer *et al*., 1998), and the types of errors made in control rooms (Jacobsson & Svenson, 1994). Minarick (1990; cited in Tamuz, 1997) describes efforts to identify accident precursors using near-miss data.

One key to collecting near-miss reports is a no-fault reporting system, often with anonymity or immunity (Baram, 1997; Marx, 1998; Tamuz, 1997). Due to problems with implementing and benefiting from near-miss reporting (Garma, 1997), considerable effort has been made to improve these systems. Phimister *et al*. (2000) note that often potential problems may be noticed either through a near-miss incident that is not reported as such or through hypothetical thinking (i.e., what if someone doesn't see that pipe as they are walking by?); they suggest that the definition of *near miss* be expanded to include such situations, as follows: an opportunity to improve safety practice based on a condition, or an incident with potential for more serious consequence. Under that definition, a variety of conditions or observations can lead to near-miss reports, including the following (Phimister *et al*., 2000; p. 11):

- Unsafe conditions
- Unsafe behavior
- Minor accidents/injuries that had potential to be more serious
- Events where injury could have occurred but did not
- Events where property damage resulted
- Events where a safety barrier was challenged
- Events where potential environmental damage could result

In the absence of concerted effort or requirements, however, near misses and even minor incidents are rarely reported and documented. Indeed, an increase in near-miss reporting is usually an indicator of improved safety awareness and safety efforts in an organization (Phimister *et al*., 2000); changes across time in near-miss reporting rates within an organization may have some value for predicting problems, but there is no reason to expect a simple relationship (such as a positive correlation) between near-miss reporting rate and later performance problems. For example, as shown in Figure 5-1, the number of lost-time injuries at Norsk Hydro decreased (from over 200 to less than 50 per year) as the number of near-miss reports increased (from 0 to over 1000 annually) over a 10-year period (Jones *et al*., 1999, cited in Phimister *et al*., 2000).

An EPRI survey of 9 energy companies with regard to switching-related incidents found that programs for near-miss reporting were in place at all sites (EPRI, 2001c). Program duration varied, with programs at four of the companies developed only within the last 4 years. Motivation for reporting may be low, with only two of the companies offering limited immunity from discipline for employees who file a report. Responsibility for follow-up resided primarily with the involved work units. Although most companies claimed to keep some log or database of reports received, only two were described in the report as having sophisticated computerized databases. Given the motivational problems and the minimal central, computerized archiving of reports indicated by the survey, the data collected at most of these companies probably would not support detailed analyses of contributing conditions.

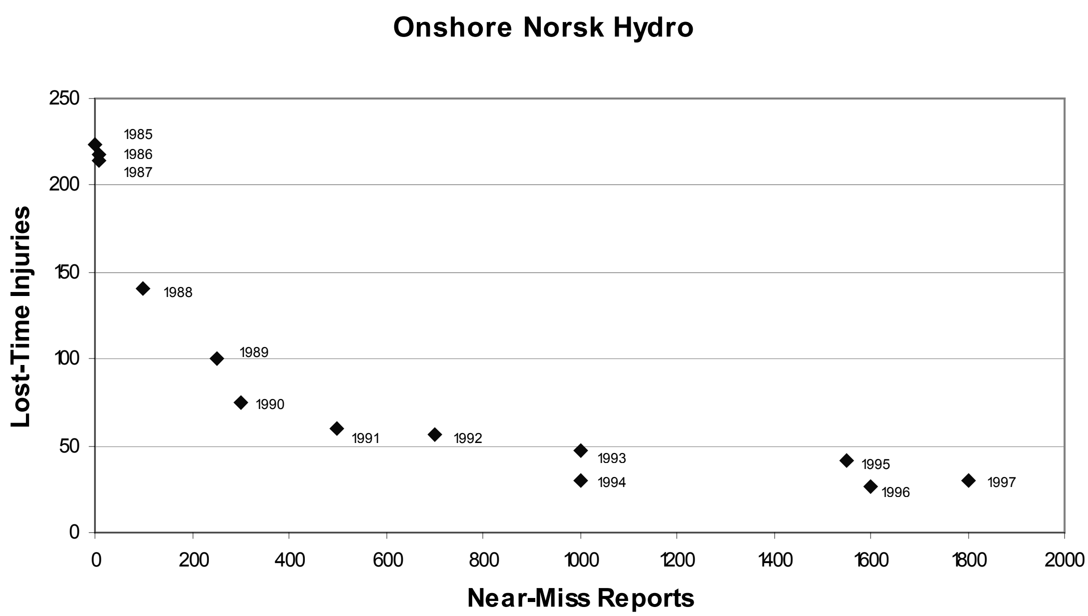

Figure 5-1
Near-Miss Reports and Lost-Time Injuries at Norsk Hydro, 1985-1997 (source: Jones *et al*., 1999, cited in Phimister *et al*., 2000)

Thus, despite the potential usefulness of near misses for learning about organizational conditions and predicting problems in advance, the predictive value of near misses has been neither studied nor exploited in many industries. This represents a fertile area for future research activity.

For the current HPM project, however, it is clear that incident reports (rather than simulator data or near misses) would be the most direct and available data on human errors at energy facilities. Incident reports, which reflect events occurring at discrete, separated moments in time, will need to be placed in the context of ongoing routine and chronological plant and organizational status. Figure 5-2 illustrates such a context for use of incident reports and other information sources in organizational epidemiology.

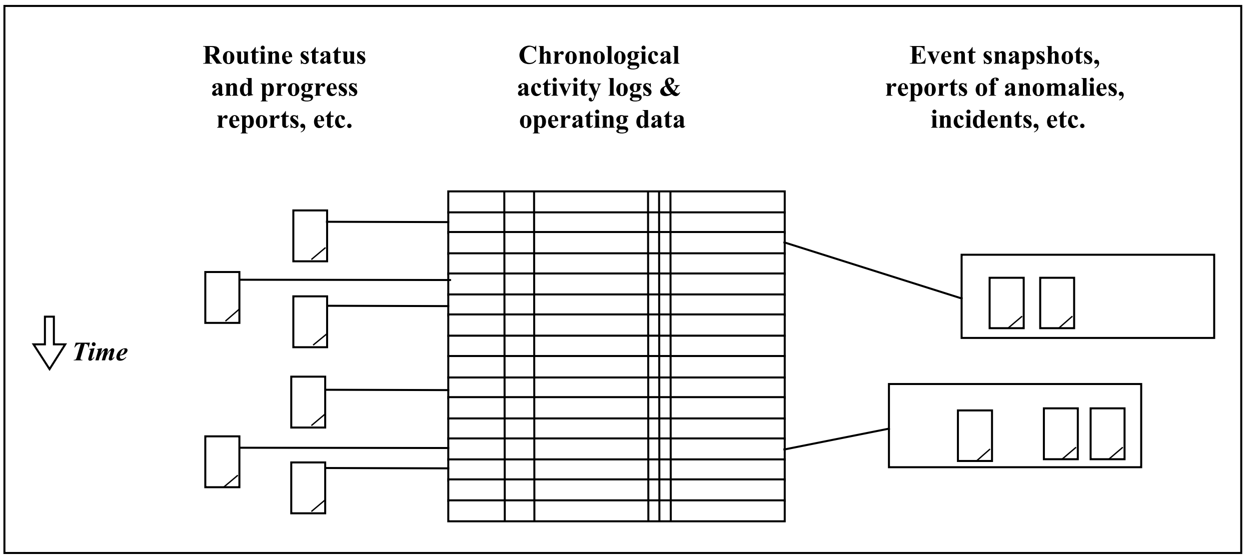

Figure 5-2
Dataset for Organizational Epidemiology Consisting of Chronological Logs, Routine Status Information, and Incident Reports

6
DATA ANALYSIS

Coding of Incident Data

Conceptually, the simplest use of incident data is for counting and trending. Certainly, it is important for a plant or facility to keep track of the number of incidents per unit of time in order to see if conditions are changing and to compare rates against other facilities or an industry average. Most analysts, however, improve the diagnostic value of their trending through some form of categorization.

The key to incident analysis—but also a potential weak point—is the categorization or description scheme applied to individual incidents. Rare major accidents are often treated as unique events, and exhaustive investigations have been carried out to understand the underpinnings of disasters such as Chernobyl, Bhopal, or the Challenger explosion; people are still writing about Three Mile Island 20 years later (Maddox & Muto, 1999). Sometimes even serious near misses—problems that do not cause accidents because system defenses are adequate—trigger major investigations into operations, as was the case with a 1999 review of the NASA's Space Shuttle sub-system and maintenance practices (Space Shuttle Independent Assessment Team, 2000). In order to generalize across incidents, however, and to be able to compare and combine results, various descriptive systems have been developed. The U.S. nuclear power industry uses causal category systems from INPO and from the NRC; different systems are used by overseas nuclear power industries, and others are used in other industries.

In general, any coding scheme acts as a bottleneck or filter: once an incident has been reviewed and coded, most multi-incident analyses rely on the coding. To the extent that the set of codes available covers areas of interest without problematic overlap, ambiguity, or omissions, further analysis is greatly simplified. Causal checklists or other codes can be very helpful for training investigators and for providing reminders during an investigation. But coding schemes often reflect either theoretical perspectives or current practical concerns (Ayres *et al*., 1992). Checklists can mislead an investigator into thinking that all possible causes or factors are considered. Changes in perspective or interest can require laborious recoding of previous incidents—if the information is still available. Studies show that there is a strong tendency for post-accident reviewers to assign responsibility to human error, even if it is not the most appropriate focus (Morris *et al*., 1999).

Significant events often receive in-depth analysis in order to uncover causes and identify possible corrective actions. A common approach is some form of root-cause analysis (RCA). Guidelines for RCA are used by the NRC (Goodman, 1997), INPO, the French nuclear power industry (Pedrali & Cojazzi, 1994), and the DOE (Collopy, 1996), as well as for aviation maintenance (Hibit & Marx, 1994), aircraft accidents (ICAO, 1993), and oil refineries

(Stockholm & Retson, 1997). Commercial versions are also available (e.g., TapRoot, as described by Hutchins [1995]; REASON, available from Decision Systems, Inc. [undated]). RCA guidelines frequently incorporate coding systems for causes and contributing factors, as well as for describing the situation and events; for example, the DOE Guideline (1992) provides 32 cause codes sorted into seven categories.

Many analysts have tried to develop and apply discrete and exhaustive error categorization systems for human error data. Fitts & Jones (1947) divided aircraft pilot errors into substitution, adjustment, forgetting, reversal, unintentional activation, and inability to reach. Lee *et al*. (1996) divided the human causes of nuclear reactor trips into wrong time, wrong type, wrong object, wrong sequence, omission, quantitative lack, qualitative lack, commission, and unskilled performance. Pyy *et al*. (1997) used a taxonomy from Swain for nuclear power plant errors, including omission, commission, wrong direction, wrong set point, and other.

The NRC supported development of guidelines for incorporating human reliability analysis into (prospective) probabilistic risk analyses, as well for retrospective evaluation of events (NRC, 2000). The result, ATHEANA (**A T**echnique for **H**uman **E**vent **A**nalysis), emphases the importance of performance-shaping factors (PSFs) as the context for human errors. A list of "commonly used PSFs" is provided (see below), but the guidelines document is more concerned with the process than with specific checklists:

- Procedures
- Training
- Communication
- Supervision
- Staffing
- Human-system interface
- Organizational factors
- Stress
- Environmental conditions
- Strategic factors such as multiple conflicting goals, time pressure, and limited resources

Some coding systems are based on models of certain aspects of human behavior. For example, as discussed earlier, errors can be categorized using the SRK (skill-based, rule-based, knowledge-based behavior) model, which was developed by Rasmussen in the context of diagnostic trouble-shooting and was later extended by Lehto (1991; see also Ayres *et al*., 1993) to errors in other domains by adding judgment-based behavior as a fourth level. A system developed by Rouse and Rouse involves behavioral processes: observation of system state, choice of hypothesis, testing of hypothesis, choice of goal, choice of procedure, and execution of procedure (Park, 1997).

In some cases, error categorization or coding schemes have been combined with sets of suggestions for corrective actions, based on prior experience and/or expert judgment. Drury *et al*. (1997) describe plans for a proactive error reduction system that would help investigators of aircraft maintenance accidents in assigning cause codes to an incident and then in reviewing selected solutions.

Context Levels

Another dimension of categorization concerns the locus of the effect or the level at which a factor operates. Errors are sometimes grouped using some version of the SHEL model (software, hardware, environment, and liveware), perhaps by adding management as an additional level (e.g., Kawano, 1996). A related division was used in an examination of mining errors (Shaw & Sanders, 1989) and in the onion model of Wreathall (Wreathall *et al*., 1991) and Reason (Reason, 1990; see also Yoshio & Inoue, 1993). Similarly, Bradley (1995) reviewed investigations of major accidents and sorted errors into operators, management, design, and other categories.

There is growing recognition that human errors need to be examined in context, rather than just sorted by cognitive processes such as omission and substitution (e.g., Moray, 1992; Stanton & Baber, 1996; Stockholm, 1997). Some add performance-shaping factors to human error probabilities (e.g., Park & Jung, 1996; Lin & Hwang, 1992) or multiply by an organizational influence factor (Mosleh *et al*., 1997). Corrective action programs are aimed at multiple levels, including teams and managers as well as individual workers (Colas, 1998; Muschara, 1997). Failure to follow procedures, for example, may be seen as a symptom of organizational problems rather than a problem in itself (Moody, 1995).

Certainly, there are important observations and interventions to be made at each of the contextual levels of workplace, team, organization, and external environment. Human factors need to be considered in the design of the workplace (e.g., Halbert *et al*., 1997; Herrin, 1997) and in the cooperative work of teams (e.g., Edmondson, 1997; Harris, 1994). Addressing organizational/ managerial variables needs to be done not instead of, but rather in conjunction with, the other levels of context, given that influences at various levels are often interrelated (Bier, 1997; Carroll, 1997; Paté-Cornell, 1997). This is also the conclusion of work using influence diagrams to study the factors that contribute to accidents such as in marine platforms (Bea & Moore, 1994; Moore, 1990).

There is justification, however, for placing new emphasis on the organizational/managerial level in the search for antecedent conditions of human error. As Reason (1997) has suggested, it is important from a practical standpoint to focus error control efforts at the levels where they will be most effective. That rules out such real but unworkable influences as changes in prevailing economic conditions (of which industry analysts may need to be aware as potential antecedent conditions, but which cannot readily be manipulated). It also raises the question of whether it is easier to deal directly with the myriad of errors possible by workers or instead with the conditions under which work is performed. (See EPRI [2001b, 2001d] for discussions of potentially useful approaches to improving human performance in organizational settings through the management of organizational factors.)

Analyses of major events typically find that the errors of one or more people at the *sharp end*—the errors that directly precipitate an accident—are only part of the total accident sequence (Reason, 1998). Numerous organizational problems (e.g., procedures, supervision, corrective actions, safety practices) were suggested to lie behind such recent problems as the PG&E blackout in San Francisco in 1998 (Chiu, 1999), the Tosco refinery explosion in 1999 (U.S. Chemical Safety and Hazard Investigation Board, 2001), and the criticality incident at the Tokaimura fuel-rod processing plant (Reason, 2000). The implication should not be that management ought to be blamed in all such incidents, but rather than management is the appropriate level to implement interventions that can deal with problems such as complacency (Freudenberg, 1992).

In complex, well-defended systems, individual errors rarely lead to severe consequences because the depth or redundancy of defenses usually limits the effects of individual errors. It is only when various problems co-occur, such as latent errors in the defenses along with the active errors of the workers (or alignment of holes in Reason's Swiss-cheese metaphor), that the unexpected or "impossible" accidents occur (Wagenaar & Groeneweg, 1988).

It may be that focusing on the organizational context is the only hope for understanding and addressing some of the paradoxical aspects of worker behavior and workplace design. For example, it has been widely pointed out that the enormous and costly growth and deployment of information technology in the last several decades has not yielded corresponding improvements in productivity (National Research Council, 1994), and many of the mitigating factors appear to involve organizational variables.

Similarly, some researchers claim to find evidence of risk homeostasis in many situations: changes in equipment or environment may not produce the intended improvements in individual safety because individuals maintain a roughly constant level of risk in their behavior (e.g., by driving faster if they wear seat belts; see Trimpop & Wilde [1994]). Thus, safety or productivity interventions aimed at individuals may fail to yield the desired effects unless systematic changes also are introduced in the social or organizational environment.

7
CANDIDATE ANALYTICAL METHODS

When this review was initiated, it was hoped that instances of state-of-the-art analyses of incident and background data would be located. Unfortunately, it does not appear that statistical analyses to date of human error have gone much beyond trending and simple two- or three-way associations.

One exception is the use of multivariate regression techniques with vehicle accident data. For example, in an examination of all-terrain vehicle accidents, the U.S. Consumer Product Safety Commission collected and coded data on accidents, as well as on the background or exposure values among the population that uses these vehicles. It was found that the risk of an accident was significantly associated with a series of predictor variables, such as the age and gender of the vehicle operator (Scheers *et al*., 1990). Donelson and colleagues (Donelson *et al*., 1994; Donelson *et al*., 1996) have used innovative statistical regression methods to model the temporal and causal structure of motor vehicle accidents and their consequences; elements of the models relate to driver attributes and characteristics, driving behaviors, environmental circumstances and conditions, and types and manners of collisions. Such analytical methods are valuable to temper conclusions that might be drawn from simple trends or from looking at a single predictor variable (e.g., Kalinowski *et al*., 1992; McCarthy *et al*., 1993).

With a larger number of variables, however, multiple regression analyses become more difficult. Techniques such as neural nets have been explored to search for optimal coefficients for variables. A major challenge with high dimensionality is to find ways to collapse or reduce the variables. Possible tools to explore include chaos theory, nonlinear dynamic modeling, genetic algorithms, and cluster analyses. Detailed consideration of statistical analytical techniques is beyond the scope of this review, but some preliminary observations can be made.

Assuming that the causal links that lead to accidents in complex organizations are themselves quite complicated—and given that an enormous amount of data may need to be processed and reduced to find such links—it follows that the task of understanding accidents in complex organizations may not lend itself readily to unaided human intuition and insight. This is where analytical tools may be able to help.

Consider the task of predicting the stock market. Without insider information, most people are unable to predict stock movement with enough accuracy to consistently beat overall market movement. Attempts to find projectable trends in the movement of a single stock are fraught with danger. Yet a truly atheoretical approach using advanced pattern detection techniques applied to massive streams of data has reportedly proved successful (the Prediction Company, as described in Bass [1999]; see also Kelly [1994] on nonlinear dynamic financial models).

Another set of tools that can help with complex problems has been developed in work on scientific visualization. Large multidimensional arrays of data may not yield their secrets to routine analyses when no theory or prior findings are available to guide the search. Sometimes, however, collapsing data and representing the data in several spatial dimensions can allow a human observer to detect potential complex patterns, which then can be tested by directed analyses. A variety of such *icon plots* have been explored, such as pie charts, starts, and polygons.

An elaborate form of icon plot that is intended to draw on extensive innate and learned human information processing involves transforming a series of data values into the dimensions of faces, typically Chernoff faces (Chernoff, 1973). Considerable research has been devoted to the ways in which various dimensions of schematic Chernoff faces are either easily separated or typically integrated when perceived, although it has been difficult to establish that the faces have an advantage over other icon plots (e.g., Morris *et al*., 1999).

8
PROSPECTS FOR ENERGY INDUSTRY APPLICATIONS

Based on the review of human error and performance at work, it does not appear that any previous attempts have been made at organizational epidemiology, as advocated by Rosenthal (in Hale *et al*., 1997).

As a starting point, the most immediate task is to obtain and organize data from one or more energy facilities. Collection and organization of a sample data set requires combining different types of data collected from different parts of the work organization. This involves working closely with one or more organizations that are willing to provide data (and possibly allow additional measures to be collected).

Defining Indices of Interest

In order to pursue the primarily inductive, or bottom-up, approach planned for the HPM project, an effort was made to review the types of information normally collected and archived at energy facilities. At two nuclear power plants and two fossil power plants, several days of interviews were conducted per site with a variety of technical and managerial personnel. Interviewers spoke with senior management and other personnel responsible for areas such as the following:

- Maintenance (corrective and preventive)
- Reliability and quality assurance
- Human resources and personnel
- Health, safety, and first aid
- Training
- Work control, work orders, and outage management
- Operations
- Information technology and document control

All interviews were conducted by at least two members of the HPM project team (including at least one psychologist experienced in the use of structured interviews), and at least one representative from the interviewee’s organization was present to provide liaison report. Based on those interviews and discussions and a synthesis of results across the four sites involved, *indices of interest* were identified as shown in Table 8-1. It is not expected that all of these types of data could be obtained at a single site.

Table 8-1
Indices of Interest for Organizational Epidemiology Studies That Are Likely to be Available at Energy Facilities

Measures	Indices of interest
Error-related	Events, incidents, injuries, errors Investigations, root cause codes, apparent cause codes Corrective actions Problem observations Positive behavior observations
Facility-related	Facility performance data, service records Equipment trip records Facility history
Worker-related	Total hours, overtime hours Shifts and work schedules Absenteeism, lost work days, voluntary departures Worker demographics, years of experience, promotions Training scores and records Hiring, retraining, job succession
Work/task-related	Project and budget overruns Operator workarounds Procedural changes (including temporary) Preventive maintenance actions Corrective maintenance Complaints, suggestions, human resource concerns Work orders, parts availability Clearance, tag-outs
Management/ Organization-related	Departmental self-evaluations Surveys Evaluations by external regulatory agencies Safety programs Human performance improvement efforts Audits, surveillance

The indices include typical error-related measures, such as events, incidents, and injuries, as well as investigation reports and RCAs. The non-error measures are grouped according to the onion model.

In general, many externally as well as internally generated human performance indicators are available at U.S. nuclear power facilities (and are undergoing review for their usefulness in planning; see, e.g., Gilbert [1997]), whereas fossil power plants generally tend to collect fewer records. Problem observations (e.g., log reports of unsafe behavior or unsafe conditions) could serve as near-miss information, especially with the expanded definition proposed by Phimister *et* *al*. (2000). Rates for observing good behavior could be useful reflections of facility safety practices and might predict performance changes if the data collection process did not change across time; another possibility is that the implementation of a program to observe and reinforce good behavior could lead to improved facility performance (presumably one of the aims of such a program). Information regarding corrective actions could be useful as well; for example, failure to implement recommended corrective actions in a timely manner following an incident could lead in various ways to performance problems—or could reflect underlying problems.

Next, the indices include facility-related measures. These could be useful in several ways. On the one hand, productivity and facility performance can be viewed as outcomes; given the assumption that human performance changes affect such outcomes, it is reasonable to look for predictive relationships between various ACHEs and eventual facility performance. On the other hand, workplace conditions plausibly affect facility personnel; for example, equipment problems are likely to increase workload and stress. Thus, information about facility-related conditions and performance logically could be valuable either as predictors or as outcomes.

The indices also include a variety of potentially interesting types of data on the context in which errors occur. Worker-related information would come primarily from personnel and payroll records and from training records; based on inquiries to date, the privacy concerns of facility management would appear to prevent analyses that would tie data from individual workers directly to error reports, but it might be possible to use measures aggregated at the department level. Work/task-related indices would come from various departments concerned with maintenance, operations, and work management; these indices could reflect sources of strain or heavy workload, as well as how successfully concerns and problems are addressed.

The most difficult indices to find are those related to organizational/managerial factors. Although organizational factors likely to influence human performance have been identified, as described earlier, energy companies seem to collect few explicit or direct measures of these factors. Some indirect indicators of organizational policy may be found, such as changes to budgets for human performance or safe behavior programs. For the most part, however, the role of organizational factors must be revealed through their effects on facility-, worker- and work/task-related measures.

Lessons from the Predictive Validity Study

The prospects for obtaining and analyzing data in an organizational epidemiology study can be gauged, to some extent, by results of the “Predictive Validity of Analytical Indicators” (PV) project, as described in *Predictive Validity of Leading Indicators: Human Performance Measures and Organizational Health* (EPRI, 2001b). Key results of the PV project, a significant element in the Strategic Human Performance Program, are summarized below.

The research team attempted to identify measures corresponding to the seven top-level cultural themes that had emerged from a review of models of organizational and human performance (EPRI, 1999b, 2000b; Wreathall & Jones, 2000), as well as outcome or criterion measures to be predicted from the leading indicator measures. One nuclear power plant participating in the PV project, which used the previously published guidelines (EPRI, 1999b) to select candidate leading indicators, began collecting data late in 1999; it is too soon to judge the usefulness of the data.

The other participating nuclear power plant collaborated in a process similar to what is being proposed here: reviewing the types of information already collected and archived at the plant to see what might be available for a historical or retrospective analysis. Out of an original list of over 60 proposed leading indicator measures, it was determined that data were available for only 21 on a monthly basis, with the period covered ranging from more than 50 to fewer than 36 months. Similarly, the list of 22 candidate outcome measures was reduced to only three. The others generally had too few observations over the study period to permit robust statistical analysis (e.g., zero “significant events,” usually 0 or 1 reportable injuries or accidents per month).

A narrative was created by plant personnel to capture changes in management priorities and organizational activities during the time period covered by the data. Considerable effort was devoted by the project team to construct a data set from the various data files and source materials supplied by the plant personnel.

The first set of analyses explored which leading indicators, if any, were significantly correlated with the selected outcome measures and, if so, at what lead-time. The most useful outcome measure turned out to be the WANO (World Association of Nuclear Operators) plant performance index, an industry-standard composite of plant performance parameters. Moderate to strong correlations were identified between two forms of the WANO index (rolling average and pure monthly) and many of the indicators at different lag-times.

The second set of analyses explored the extent to which outage performance could be predicted by indicators in the months leading up to outages. During the period of approximately 4 years for which historical data were available, the plant had gone through several planned outages, each lasting about 2 months. Outages at nuclear power plants are characterized by heavy workloads and management challenges, with a great number of tasks to be coordinated and conducted before the plant can be brought back on line. One of the outages was considered by plant personnel to have been especially difficult, running 25% over schedule; the subsequent outage was completed somewhat ahead of schedule and was considered very successful.

The researchers compared measures (both indicator and outcome) from a period preceding the difficult outage with a period preceding the good outage. They found a number of statistically significant differences between the two periods that had plausible interpretations. For example, the difficult outage was preceded by higher numbers of open temporary modifications, a higher corrective maintenance backlog, and a higher number of work orders (action reports); it was also preceded by a lower number of man-hours and a lower training budget than the later period. Although it would be inappropriate to draw specific causal conclusions from these observations, it appears that these indicators may hold some promise as leading indicators or antecedent conditions of human and facility performance.

In summary, this exploratory work indicates that leading indicators may predict important performance outcomes in ways that current and lagging indicators cannot. The PV study also reached several conclusions about the difficulties of reconciling research interests (methodological issues) with the real-world operation of a nuclear power plant or other energy facility:

- Consistent data streams are required for both predictors and outcomes over an extended period of time.
- Significant variability is required within the predictor and outcome data streams.
- Data are required from several facilities to test the external validity (generalizability) of the leading indicators.

Knowledge of other variables that may influence the outcomes is required, as is statistical control of these variables.

9
PERSPECTIVE

There is broad consensus for the influence of organizational factors and other antecedent conditions on subsequent human performance in work settings and, thereby, on outcomes such as productivity and safety. Very little empirical work has been done to date, however, to uncover such antecedent conditions in energy industry operations or to test the predictive usefulness of measures that reflect these antecedent conditions.

The strategic “Predictive Validity of Leading Indicators” study has underscored the difficulties of empirical research in this area, but it has also shown that antecedent conditions for human error (ACHEs) may prove useful for managing facility performance (EPRI, 2001b). Therefore, drawing upon the lessons from this literature and background review and the recent study, the following configuration is recommended for a comprehensive research program:

- Obtain monthly data for a wide variety of candidate ACHEs (listed in Table 8-1) from several participating energy industry sites
  - The use of a wide variety of variables will permit exploration of possible unanticipated relationships.
  - The use of several sites will permit exploration of the generalizability of both the analytical process (e.g., whether time-lagged correlations can be found at more than one facility) and the particular findings (e.g., whether the maintenance backlog tends to be a good predictor at more than one facility).
- Explore numerous analytical approaches
  - Simple trends and univariate plots are needed for reviewing the data to make sure there are no anomalous entries that could distort analytical findings.
  - Time-series analyses can search for predictive relationships between the measures.
  - Multivariate techniques are needed to look for emergent patterns, including combined or interactive effects of multiple factors.
- Work closely with personnel from the participating facilities
  - Their assistance will be needed for obtaining the data as well as for reviewing the plausibility of the findings.
  - They will have valuable insight into facility history and factors that might account for some changes across time in the measures.

These recommendations have been implemented to the extent possible in a study of human performance at fossil power plants (an EPRI final report on the study [1004669] is scheduled to be available by late 2002). The results to date demonstrate both the difficulty of implementing these recommendations and the promise of new insights that can be gained regarding antecedent conditions for human and facility performance changes.

Implications for Organizational Epidemiology

The energy industry in the United States, and the U.S. nuclear power industry in particular, can point to an admirable safety record with respect to acute injury. Although several highly scrutinized events have occurred, the acute injury problems associated with energy facility operation have generally been similar to industrial operations in general—despite the pervasiveness of electricity infrastructure and the enormous potential risks associated with nuclear generating facilities.

The long-running debate (Sagan, 1993) between the high-reliability-organization theorists (who say a complex organization can be run with virtually no catastrophic errors by means of defenses) and the normal-accident theorists (who say that accidents are inevitable in complex, tightly coupled systems) may come down to a difference of perspective. Most observers agree that high reliability requires substantial effort; difference of opinion involves the degree to which a strong organizational safety culture is attainable in a nonmilitary setting solely by self-scrutiny and external regulation (Gaba, 1997).

Complex high-risk work organizations need to continue their efforts to improve and maintain their defenses in depth, to address problems at the individual and workplace levels, and to monitor attitudes and organizational climate. Behavioral safety interventions (e.g., Geller *et al*., 1996; EPRI, 2001a) and comprehensive safety programs (e.g., Edkins, 1998) will continue to play important roles in maintaining safe operations. But the risks of accidents may increase as the energy industry faces challenges in the 21st century, such as changes in regulatory oversight, competitive pressure, and experienced workforce availability.

Exploration of new analytical techniques may uncover the hidden patterns that represent antecedent conditions for human performance problems. Such analytical foresight and the attendant predictive capability could help facility managers maintain and improve the safety and productivity of electric power generation and delivery.

A
INTRODUCTION TO ANNOTATED BIBLIOGRAPHY

The literature and background review was planned as an effort to survey relevant technical literature and state-of-the-art human performance data collection, handling, and analysis practices for and in industry and government. A truly exhaustive or comprehensive survey of possibly relevant literature would be a monumental task; furthermore, there would be extensive overlap with other reviews and compendiums, as noted in Section 1 of this report.

Nevertheless, a considerable volume of literature was reviewed. To help users in identifying work of potential interest, each reference was assigned to one or more categories according to subject matter (the categories, which are defined below, include Control Room, Databases, Evaluation, Human Error, Performance, Modeling, Methodology, Risk, and Safety). In addition, short descriptions or summaries were prepared for each reference.

Appendix B organizes the references by category to simplify the search process for those using this annotated bibliography in hard-copy form (as opposed to doing keyword searches in the electronic file); under each category heading, references are listed by date.

Appendix C contains the annotated bibliography itself, with references listed in standard alphabetical order. Category labels assigned to each reference are also provided.

The categories are described below:

- **Control Room**: addressing human factors and design of the control room, stress in the control room, and control room technology development.
- **Databases**: addressing the construction and use of incident or other databases for prevention of accidents.
- **Evaluation**: evaluating safety culture, risk factors, and system performance in organizations.
- **Human Error**: addressing the identification and prevention of human errors.
- **Performance**: addressing human performance issues related to organizational safety.
- **Modeling**: addressing the development and use of models in human factors design and accident prevention.
- **Methodology**: addressing methodology used in modeling, safety culture evaluation, and human error identification.
- **Risk**: examining aspects of risk in human actions or errors.
- **Safety**: examining issues in human and organizational safety.

B
REFERENCES BY CATEGORY AND DATE

In this appendix, the references included in Appendix C are organized according to the categories listed in Appendix A.

Under each category heading, references are listed by date, starting with the most recent (undated references appear at the end of each list); other category labels assigned to individual references are also provided.

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[Performance]

Provides recommendations for leading performance indicators (PIs) that could be used "to predict the need for plant self-intervening action to improve performance" in three crosscutting areas: human performance, safety consciousness, and problem identification/resolution. Based on a regulatory oversight framework from the NEI, these three issue areas presumably span a range from initiating events through mitigation, barriers, and emergency preparedness to radiation safety and safeguards (respectively). Characteristics for basic LIs are discussed (e.g., have a significant bearing on plant operation/maintenance, be understood easily/consistently, be quantitative and consistently measured over time). Suggested PIs with connections to one or more of the three issue areas fall into four groups: problem self-identification (e.g., % of problems attributed to a department that are identified by the department itself), repeat work (e.g., quantity of design document revisions as % of quantity of design documents originally released), backlog and timeliness (e.g., quantity and age distribution of backlogged work), and other (e.g., accidents, radiation exposures, security events, overtime rate, absentee rate). The document does not discuss the source or rationale for recommending these PIs.

Andersen, A. (1998) "Development and findings of the performance trending methodology." Prepared for U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Regulatory Research, NUREG/CR-6618.

[Evaluation, Safety]

Work was conducted to help identify plants that should be brought up for discussion at NRC senior management meetings. Four analytical approaches were considered, developed, and evaluated; a trending model based on the number of variables for which each plant is among the worst performers was found to be the best (least effort, best prediction). A total of 20 variables was considered for inclusion in the trending model; 7 were selected as being most relevant to safety and most timely: forced outage rate, equipment forced outage rate, safety system failures, and cause codes for administrative, maintenance, design, and other personnel error. These are part of the NRC performance indicator program.

Apostolakis, G. E., Bier, V. M. & Mosleh, A. (1988) "A critique of recent models for human error rate assessment." *Reliability Engineering and System Safety*, 22, 201-217.

[Modeling]

Human error rates are modeled either based on errors per time available (the NRC handbook, or the Human Cognitive Reliability model), or by using ratings by experts (the Success Likelihood Index Methodology - Multiattribute Utility Decomposition [SLIM-MAUD]). The authors find methodological problems with each approach.

Auflick, J. L., Hahn, H. A. & Morzinski, J. A. (1997) "Development of an integrated system for estimating human error probabilities." Presented as a poster at the Human Factors and Ergonomics Society 41st Annual Meeting.

[Modeling]

Describes research at Los Alamos National Laboratory. Describes a new knowledge-based expert system for HRA (human reliability analysis) designed to help with the assessment of human error probabilities (HEPs) for specific human error actions. It incorporates well-known core HRA techniques (HCR, or Human Cognitive Reliability; THERP; ASEP, or Accident Sequence Evaluation Program) and a new Bayesian method.

Ayres, T.J. & Bryant, L. (1989) "Training for Spacecraft Technical Analysts." *Proceedings of the Human Factors Society 33rd Annual Meeting*, 1263-67.

[Evaluation, Modeling, Control Room]

Describes work in cognitive task analysis conducted with spacecraft technical analysts at the Jet Propulsion Lab (JPL). Networks derived (using PATHFINDER) from similarity ratings by members of the temperature subsystem team revealed large differences in imputed mental models between the different analysts. This poses problems for efforts to create useful expert systems as decision-support tools. Recommendations are made for training methods to accommodate an anticipated transfer of control from a contractor to JPL personnel for the Magellan mission.

Ayres, T.J., Gross, M.M., & McCarthy, R.L. (1993) "A Retrospective on Attempts to Reduce Vehicular Risk Through Operator Training." The American Society of Mechanical Engineers.

[Evaluation, Safety]

A review of studies of driver training effectiveness shows that such programs have not been found to reduce accident rates. An explanation is proposed, based on a model of human error that includes attitude-, knowledge-, rule-, and skill-based behavior: Most vehicle accidents in the data reviewed involve attitude-based errors and to a lesser extent rule-based errors, whereas driver training typically focuses on transferring knowledge and (to a limited extent) developing skills. It is suggested that safety programs need to address behavior change more appropriately.

Ayres, T., Gross, M., Wood, C., Robinson, J. & Merala, R. (1992) "Risk analyses for agricultural vehicles." Presented at the annual meeting of the American Society of Agricultural Engineers, Paper No. 921609.

[Safety]

Analysis of accident data for agricultural products and activities can provide important information for product design and safety policy. A review of accident analyses for tractors and other agricultural products reveals a variety of approaches that can be taken. Problems facing each method are discussed, and recommendations for future work are provided.

Baram, M. (1997) "Safety management challenges posed by organizational learning and organizational change." M.I.T. Conference on Organizational Processes in High Hazard Industries, http://stsfac.mit.edu/projects/risk/reports/intro.html.

[Evaluation, Safety]

Near-miss evaluation is required by the Process Safety Code of Management Practices (Chemical Manufacturers Association), the Process Safety Management Standard (OSHA), the Risk Management Program Rule (EPA), and the Directive on Control of Major Accident Hazards (European Union). Problems with implementing and benefiting from a near-miss reporting systems include appropriately defining near misses, getting reports despite personal disincentives for employees, dealing with legal implications and other factors that determine management attitude, evaluating the seriousness of risks, determining the type/level/timing of corrective actions, obtaining adequate resources for corrective actions, and preventing corrective actions from destabilizing the safety management system.

Bareith, A., Karsa, Z., Spurgin, A.J., Kiss, I. & Izso, L. (1994) "On the Use of Data Collected During Crew Reliability Experiments at Paks Nuclear Power Plant—Status Report." *Proceedings of PSAM - II*, 87-1 to 87-6.

[Modeling, Database]

Under the framework of a joint U.S.-Hungarian project, the first ever operator reliability experiments for a Soviet-design, VVER-type reactor were carried out at the Simulator Center of the Paks Nuclear Power Plant. The primary objective was to provide input to the ongoing probabilistic safety assessment of the Paks plant and to provide insights to be useful as far as training and operation is concerned. The data collection was based on the extension of the methodology developed by EPRI under the Operator Reliability Experiments (ORE) project (see EPRI report NP-6937). Five accident scenarios were selected for the experiments. The experiments covered 120 simulator sessions. A comprehensive data bank was created during the simulator session. The data analysis methodology is based on the ORE project. A major finding of the initial data analysis is that most of the human interactions fit standard distributions. This is in accordance with the results gained from the ORE project. However, for the Paks data, the categorization scheme based on human cognitive behaviors does not seem to be appropriate at this time. No specific correlations were found for these categories. The differences in the distribution of response times representing different levels of cognitive information processing (S-R-K) are not meaningful. This may be because crews mainly rely on knowledge to diagnose and respond to accident sequences, with procedures used as a backup. Three generic correlations were developed in the ORE project based on procedure logic. For the Paks data, the use of such categories also seems questionable because of the way the crews operate and use the procedures. The analysis of the control charts shows that the crew responses are, for the most part, very consistent. However, comparisons made between control plots do not indicate transfer of skills from one crew to another. A detailed analysis of the causes of the crew deviations has resulted in the development of a causal hierarchy. This relationship can usefully be applied for both HRA and training and operation purposes. Based on the insights derived from the distribution of deviations in the hierarchical array, a decision tree has been constructed for use in the Paks human reliability analysis. The decision tree reflects the categories in the hierarchical array along with the influence of the scenario, in terms of its effect on the ability of the crew to control the scenario. In conclusion, the results show that the EPRI data collection methodology can be applied very successfully to 440-MW(e) VVER-type PWRs. During the experiments, two developments were made to extend the capability of the EPRI approach. This was in the area of automated data collection, using the Computer Operator Assessment System (COPAS) system, and an increase in the observer data. Analysis of the time data indicated variable crew responses dependent on the difficulty of the scenarios, crew organization and knowledge, leadership, and procedure use.

Barnes, D. S. & Brearley, S.A. (1994) "Safety Culture: What Is It and How Can It be Developed." *Proceedings of PSAM – II*.

[Evaluation, Safety]

From AEA Consultancy Services in the UK (formerly the UKAEA or UK Atomic Energy Authority): "The underlying management and organisational failings contributed significantly to the multiple causes of these accidents." Management must develop and maintain safety culture through providing, implementing, and monitoring safety policy. Implementation includes lines of authority, guidelines for action, and documents, but also "soft" features such as the quality of inter-level communication, management visibility, perceptions, and attitudes. Makes reference to a 1991 document, "Management at Risk," SRDA-R4.

Basra, G. & Kirwan, B. (1996) "Computerised Human Error Analysis Trees (CHEAT)." *Advances in Applied Ergonomics*.

[Modeling]

CHEAT works on the fundamental premise that a diagrammatic technique illustrates clearly how an assessment has been structured and is easier to learn and apply. The application of CHEAT to a hazardous chemical transport system is documented in this paper to show how CHEAT works in a real industrial context, as well as what type of ergonomic insights can be gained from usage of this technique.

The basic Windows-based program structure has been influenced by techniques like HRMS (Human Reliability Management System), in that it is modularized in a similar format. CHEAT's "tree-like" appearance, the left to right approach, where three levels of activity can be implicitly identified, also follows the basic layout of Murphy Diagrams. Questions similar to those from Systematic Human Error Reduction and Prediction Approach (SHERPA) have been used in the actual technique. There are four core components of the CHEAT system: (1) Task analysis, (2) Human error analysis, (3) Error reduction mechanisms, and (4) Documented output table. A new error identification technique was successfully developed. However, this system needs to be extended before it can accomplish real error identification tasks comprehensively and exhaustively. The two key areas of work are the extension of the system to consider knowledge-based errors and an extension of the system to consider psychological error mechanisms. Work to extend CHEAT is currently in progress.

Bass, T.A. (1999) *The Predictors*. Holt & Co.

[Modeling]

Layman's account of the work of the Chaos Cabal, later Prediction Company, in its efforts to model various financial markets. They rely upon very heavy use of financial databases and an assortment of modeling techniques including time series, nonlinear models, chaos models in multidimensional state space, and Holland's genetic learning algorithms. Based on their having been funded for several years as an exclusive provider to Swiss Bank, it appears they have been successful at making profitable forecasts.

Bea, R. G. & Moore, W. (1994) "Management of human error in operations of marine systems." *Marine Technology Society Journal*, 28 (1), 17-22.

[Modeling]

Short paper based on a project for California Sea Grant College "to develop engineering reliability and decision-analysis procedures that would assist in the assessment and implementation of alternatives for managing human and organizational errors in the operation of tankers and offshore platforms." Accident reports came primarily from the Coast Guard, the Minerals Management Service, and the NTSB; several casualty databases were also used. The basic analytical framework used influence diagrams (citing work with Pate-Cornell). In order to assess the human errors conditional on the causative factors, they developed HESIM, the Human Error Safety Index Method, based in turn on the Human and Organizational Error (HOE) Data Quantification System (HOEDQS), which allows objective data to be combined with expert judgments. The methodology was used to evaluate alternatives for risk management. "The most important part of the HOE evaluation process is qualitative; a realistic and detailed understanding of the human, organizational, and systems aspects and potential interactions must underlie the entire process."

Benca, R. M. (1998) *Effects of Light on Behavior*.

[Performance, Evaluation]

Light influences behavior via entrainment of the circadian clock, and it has direct effects on sleep and wakefulness. The direct effects are an increase in wakefulness and alertness in humans and an increase in sleep in nocturnal animals. The direct effects of light are most apparent following changes in lighting. The effects are short-lived and depend on the magnitude of the lighting change. Advantages of the circadian rhythm vs. direct control are as follows: (1) circadian rhythms help anticipate predictable changes in lighting conditions, and (2) direct light/dark effects allow behavioral responses to rapid/unpredictable changes.

Bennett, C.T., Banks, W.W., & Jones, E.D. (1994) "The Cost of Human Error Intervention." *Proceedings of PSAM - II*.

[Human Error, Evaluation]

U.S. DOE has directed that the cost-benefit analyses be conducted as part of the review process for all new DOE orders. This policy is intended to ensure that DOE analysts can justify the implementation costs of the orders that they develop. The authors argue that a cost-benefit analysis is merely one phase of a complete risk management program—one that would more than likely start with a probabilistic risk assessment. The paper presents a series of cost-benefit analyses using historical events in the nuclear industry. Using an extremely conservative technique, a comparison is made between only the cost of a human error intervention program to that of constructing a facility and the revenues lost if that facility were to be destroyed by human error. The cost of human lives lost is not factored into the equations.

Bier, V. *Management and Organizational Influences on Risk.*

[Risk]

Suggests that corporate culture "has at least as much effect on risk as plant design." Literature on organizational structure yields key variables related to assignment of decision rights, performance measurement systems, information systems, goals and incentive systems, defensive behavior under stress, and leadership characteristics. Calls for research with improved methods to characterize and evaluate corporate culture.

Bier, V. (1997) "Illusions of safety." M.I.T. Conference on Organizational Processes in High Hazard Industries, stsfac.mit.edu/projects/risk/reports/intro.html.

[Evaluation, Safety]

Author agrees with Dowell & Hendershot (similar to Ayres *et al*., 2000, the condition of perceived affordance > actual safety) that installing a protective system can create an illusion of safety, causing people to believe things are safer just because, e.g., technical safeguards or accident investigation systems are in place. Gives examples of problem, and extends to similar effects that may be associated with organizational programs. The requirement for specifying corrective actions to be undertaken in response to incidents can add to the illusion of safety. Requiring corrective actions to be identified for every significant incident may not help if the suggested corrective actions are ineffective or impractical. Some corrective actions are promises that are difficult or impossible to implement, such as for improved cleanliness or housekeeping. Other corrective actions may have little or no impact on future risk; actions aimed at a particular employee (counseling, training, discipline, etc.) do not address plant-wide risk. Similarly, the requirement to do a root cause analysis does not guarantee that the true or effective cause for an incident is indeed identified. Refers to having found licensee event reports (LERs) “in which design errors or latent failure modes were introduced as a result of otherwise beneficial plant changes.” Notes that “major changes in system configuration may reliably eliminate certain failure modes... however, the effects of more subtle changes may be difficult to predict.”

Bier, V., Joosten, J., Glyer, D., Welsh, M. & Tracey, J. (1999) “Effects of Deregulation on Safety.” *CHPCS Sixth Annual Workshop Proceedings, Human Performance: Bridging the Gap Between Research and Practice*.

[Safety, Evaluation]

Deregulation in U.S. aviation had mixed results: Despite frequently expressed concerns, accidents caused by equipment failure and by human error declined in the early 1980s (though not to pre-deregulation levels). However, the rate of pilot error and ground crew error increased in the late 1980s. In addition, deregulation allowed numerous new airlines to enter the industry, with little experience in operation and with higher accident and error rates. Other changes in this time period included financial pressures, mergers/acquisitions, and labor relations problems. For U.S. rail, deregulation was accompanied by improved safety, but it is noted that employment cuts may have begun to affect safety. Deregulation in the UK electric industry (early 1990s) led to privatization and a 50% employment decline. Various problems have been cited; some performance and safety measures improved, others got worse (suggested as perhaps due to better reporting).

Overall conclusions: “Deregulation is not incompatible with maintaining or even improving safety; upheaval associated with deregulation poses a major management challenge.”

Bier, V., Joosten, J., Glyer, J., Tracey, J. & Welsh, M. (2001) “Effects of Deregulation on Safety: Implications Drawn from the Aviation, Rail, and United Kingdom Nuclear Power Industries.” NUREG/CR-6735.

[Safety, Evaluation]

Same as above.

Bier, V.M. & Yi, W. (1994) “The Performance of a Precursor-Based Estimator.” *Proceedings of PSAM - II*.

[Evaluation, Methodology]

In estimating the frequency of a rare event (e.g., a core melt accident at a nuclear power plant), the number of observed events is usually too small to support the development of accurate estimates by means of the usual statistical estimator. While we certainly want an estimator that is consistent, we also want it to be reasonably accurate in the short term, not only as t becomes large. The use of data on accident “precursors” or “near misses” has been suggested as an approach to achieve this goal. This paper discusses the performance of selected estimators in practice, based on the results of a simulation study.

Blackman, H.S. & Byers, J.C. (1998) “Unsolved Problem: Acceptance of Human Reliability Analysis.” *Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting - 1998*.

[Modeling]

The practice and application of human reliability analysis (HRA) have long been controversial among human factors professionals. The controversy has tended to focus on three major points: (1) the quantification of human reliability; (2) the lack of hard data for human reliability; and (3) the idea that human reliability debases humans to the level of mechanical system components, whereas the proper job of human factors is to correct system design and to optimize human performance. In quality HRA, extensive task-analytic-based qualitative analysis is conducted well before getting to any quantification. And, in most cases, that type of analysis is where the real benefit of HRA is obtained. Design flaws in hardware and procedures are caught and often corrected immediately. More importantly, recent HRA analyses are incorporating a more complete understanding of the conditions that produce errors by examining the context built by system status, as well as the attendant performance-shaping factors. In fact, the development of new HRA methods has continued with a much stronger emphasis on error identification and understanding. In addition, recent validation work is lending support to the error rates generated by the methods. However, efforts that truly integrate methods development and data collection to support quantification are still rare. Industry and government alike are turning to risk assessment to help manage and regulate high-risk technologies. And, while human factors professionals debate the relative strengths and weaknesses of HRA methods and data, these same methods and data are being routinely applied in risk assessments of high-risk technologies. The lack of acceptance of HRA by human factors practitioners means that we as a community may be missing opportunities to have a greater impact that we presently have on system design and operation. To ensure broader acceptance of HRA, several suggestions are proposed: (1) discover what is needed for HRA legitimacy; (2) review of HRA methods; (3) review and establishment of appropriate HRA use; (4) development of new HRA methods; (5) development of HRA data; and (6) assessment of the institutional issues.

Blevins, M. (1999) “Surviving Success In Human Performance Programs.” Nuclear Operations, Comanche Peak Steam Electric Station.

[Evaluation, Performance]

Does not believe success really leads to future problems because of reduced vigilance (complacency), but suggests organizations need to stay alert. Increased opacity (inability to understand how the organization works) reduces the ability to detect and deal with human performance problems. Two suggestions: lower the threshold for reporting events (or near misses) in order to maintain a data stream (some sense of how things are going, even when they appear to be going well), and develop proactive indicators such as the EPRI Nuclear “Leading Indicators” project, or the work being done on the EPRI Strategic “Human Performance Management: Database and Analysis” project.

Bley, D.C. (1998) “Data requirement for Human Reliability Analysis.” CHPCS 5th Annual Workshop: Expanding Human Performance Envelopes: Tools for Industry.

[Evaluation, Modeling]

Many conclusions have been made about serious accidents: (1) serious accidents often involve human “error”; (2) operators act rationally, but they are set up to fail by error-forcing context; (3) serious accidents are a multidisciplinary problem; (4) analysis of more operational events is needed; and (5) events from many technologies are applicable. Three points to remember are (1) data requirements are tied to the human reliability analysis (HRA) model; (2) ATHEANA, a new model for HRA, is based on a multidisciplinary view of human reliability; and (3) useful data must form an information base that explains operational events, rather than tabulating them. In summary, simple actuarial statistics do not provide the depth of information needed for meaningful analysis of past events. In addition, meaningful retrospective analysis is the basis for predictive HRA. Finally, queries and categorization replace counting and tabulation.

Blom, I., Melber, B. & Durbin, N. (1994) “Evaluation of Quality Systems.” *Proceedings of PSAM - II*.

[Evaluation, Methodology]

The importance of quality systems on nuclear facility performance has not been considered in a systematic way even though a facility’s quality processes are expected to have important effects on safety. The Swedish Nuclear Power Inspectorate (SKI), assisted by the Battelle Human Affairs Research Center in Seattle, is developing a methodology for evaluating the effectiveness of such systems. The approach is to identify factors critical to the effectiveness of quality systems in the nuclear context and to develop criteria to assess the functioning of these critical factors. These factors and criteria were developed based on expert knowledge and extensive interviews with SKI staff and Swedish nuclear facility personnel. This paper summarizes the evaluation method developed and presented in a draft handbook. The evaluation method is currently being tested by SKI inspectors. The key criteria used to judge the effectiveness of a facility’s quality system methods are as follows: (1) the system contains methods for the basic components of a quality system: problem identification, problem-solving, and standardizing solutions; (2) these methods are prevention based; (3) the methods are integrated; and 4) the methods are focused on the process and not only outcomes. A more detailed discussion of each of these criteria is available.

Boff, K. R., Kaufman, L., & Thomas, J. P. (1986) *Handbook of Perception and Human Performance, Volume 1*. John Wiley and Sons.

[Performance]

Edited resource covering background material for human factors.

Bongarra, J.P., Jr. (1997) “Certifying Advanced Plants: A US NRC Human Factors Perspective.” IEEE Sixth Annual Human Factors Meeting.

[Evaluation, Methodology]

The U.S. NRC began the process of certifying advanced nuclear power plants in the early 1990s. The design certification process requires an applicant to comply with the technically relevant portions of the regulations established as a result of Three Mile Island. One requirement is for the applicant to submit a control room design that reflects state-of-the-art human factors principles to the NRC for review before human-system interfaces (HSIs) can be built for plant locations such as the main control room and remote shutdown facility. To address this requirement, the NRC developed a Human Factors Engineering program Review Model (NUREG-0711) as guidance for the staff to use in reviewing the human factors engineering (HFE) portion of applicant submittals. NUREG-0711 is an evaluation methodology based on a design and implementation process.

To date, the NRC has reviewed applications from three designers, General Electric, ASEA Brown Boveri-Combustion Engineering, and Westinghouse Electric Corporation. Though 10 CFR Part 52 indicates that design certification may be sought for “an essentially complete design,” in practice, the designs that have been submitted for review have not been complete, especially with regard to human factors considerations. This is because of, in large part, anticipated changes in human-system interface technology that make it difficult for applicants to submit a completed design for an advanced plant that may be years away from construction. To address this challenge, the NRC has been performing reviews of each applicant’s HFE design process, rather than of the final product resulting from HFE design. To aid the NRC in reviewing less than complete designs, a unique evaluation tool—Inspections, Tests, and Acceptance Criteria (ITAAC)—has emerged from the early stages of reviewing advanced reactor designs. ITAAC consists of various inspections, tests, and analyses.

Booth, R. T. (1996) “The promotion and measurement of a positive safety culture.” In *Human Factors in Nuclear Safety*, N. Stanton (Ed.), Bristol, PA: Taylor & Francis.

[Safety, Evaluation]

Notes that “the concept of safety culture was introduced in a seminal paper by Zohar (1980), and to the nuclear safety debate by the International Nuclear Advisory Group (1988) in their analysis of Chernobyl.” The latter defined “safety culture” as follows: “that assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, nuclear plant safety issues receive the attention warranted by their significance.” More generally, safety culture can be positive or negative, and positive safety culture organizations involve mutual trust, shared perceptions of the importance of safety, and confidence in efficacy of preventive measures. No data are presented in this reference.

Bradley, E. A. (1995) “Determination of human error patterns: The use of published results of official enquiries into system failures.” *Quality and Reliability Engineering International*, 11 (6), 411-427.

[Evaluation, Human Error]

The author, a reliability analyst at ESKOM, reviews 12 major disasters (e.g., Titanic, Piper Alpha, Bhopal, Challenger, Chernobyl). Fault trees are constructed by using codes for eight error types (buying, commissioning, design, failure of equipment with no direct human attribution [fails to operate when required, or operates when it should not], management, operating, production, repair), as well as by considering avoidability (person knew better, or did not have the knowledge and experience required). The most commonly noted types in this set of 85 errors were operator error (40% of the errors identified) and management error (20%). Only 9% were equipment failures that could not be attributed directly to any human error.

Author notes that several errors related to shift changes, and several occurred in early morning hours. “The fact that operator error predominates is not surprising. Incidence of error is probably related to the amount of time available to make a decision. Operators, being at the ‘sharp end’ of the process, have on average less time to assess various options before making a decision, than designers and maintenance artisans have.”

Bradley, E. A. (1998) “Use of competitions and challenges as a means of improving operator performance and reliability.” *Transactions of Nanjing University of Aeronautics & Astronautics*, 15 (1), 115-120.

[Evaluation, Performance]

Based on a previous finding “that in large complex systems, the predominant form of human error is operator error,” Bradley advocates increased use of simulators, coupled with motivation to improve. He has organized the Operators’ Challenge, involving competition between teams from different stations on a standard simulator scenario. He suggests that a drop in the number of trips due to operator error at ESKOM (from 63 in 1994 to 7 in 1996, when total trips climbed from 224 to 264) indicates the strength of the program.

Bradley, E. A. “Large system failures.” ESKOM (unpublished).

[Evaluation, Human Error]

The analysis performed on 12 major disasters (Bradley, 1995) is extended here to six failures at ESKOM sites. In contrast to the previous results, management errors—including deficiencies in procedures and schedules and failure to complete actions recommended after audits—were the most common type of error (18 of 33). To address these procedure-related problems, ESKOM instituted a gatekeeper clause in the contracts for power station managers, by which bonuses would be reduced if the “Plant Management Fundamental Policies” were not followed.

Brown, W. R. (1997) “Implementation of a safety parameter display system in a Windows™ environment.” *Proceedings of the 1997 IEEE Sixth Conference on Human Factors and Power Plants*, 4-11 to 4-15.

[Safety]

Describes lessons learned from a man-machine interface change, including factors such as navigation, color, and font size.

Caird, J. K., & Kline, T. J. (2000) “The Relationships Between Organizational and Individual Variables to On-the-Job Driver Accidents and Accident-Free Kilometers.” *Proceedings of the IEA 2000/HFES 2000 Congress*, 3-361-3-364.

[Evaluation]

SEM (structural equation modeling) was applied to data from professional drivers in a Canadian company, using questionnaire responses as well as driving records. Variables in the model included driver adaptations (beliefs, planning, organizational support) and driver behavior (moving citations, on-the-job accidents, accident-free kilometers, speed, fatigue, errors, environment adaptations). “The present study lends support to the theoretical prediction that unfavorable organizational demands contribute to vehicle accidents (Reason, 1990a, 1995).”

Caldwell, B.S. (1998) *Classifying and Analyzing Domains of Human performance and Event Recovery*. Department of Industrial Engineering, University of Wisconsin-Madison.

[Evaluation, Performance]

Addresses the following: improving human performance in complex systems, distributed supervisory control systems, problems with “keyhole effect,” domains of expert performance, classification of operator performance events, event recovery, improving human-system interface design and adaptive automation, and defining and evaluating work culture impacts on safety performance.

Capelli-Schellpfeffer, M., Floyd, H. L., Eastwood, K. & Liggett, D. P. (1998) “How we can better learn from electrical accidents.” *IEEE No. PCIC-98-34*, 1-8.

[Database, Evaluation]

Points to the benefits of collecting databases of near misses because serious injuries tend to be so infrequent. Refers to a dataset of approximately 600 near-miss incidents involving electrical safety in a large chemical company. Various codes are entered in the dataset, but no explicit human factors codes were provided. Analysis of results helped change employee impressions regarding who is involved in incidents (e.g., electrical craft vs. other workers, contractors vs. employees) and typical conditions.

Carroll, J. S. (1997) “Beyond compliance.” M.I.T. Conference on Organizational Processes in High Hazard Industries, http://stsfac.mit.edu/projects/risk/reports/intro.html.

[Evaluation, Safety]

Cites several papers arguing that having workers comply with rules will not necessarily ensure safety. Challenges the assumptions that experts can anticipate safety problems and create rules to avoid them, and that nonexperts should simply follow such rules. Need to place some reliance on operators to deal with unanticipated situations adaptively. Centralized control may increase rule compliance but decrease intrinsic motivation of employees. Root cause analysis should be viewed not as a technical discipline supporting top-down safety control but rather as an opportunity for cross-level dialogue and collaborative learning.

Chernoff, H. (1973) “The use of faces to represent points in k-dimensional space graphically.” *Journal of the American Statistical Association*, 68 (342), 361-368.

[Methodology]

Presents rationale for encoding values of multiple variables as parameters for spatial representation in the form of simplified faces (line drawings).

Chiu, C. (1999) “Human Error Prevention to Avoid Blackouts.” *CHPCS Sixth Annual Workshop Proceedings*.

[Human Error, Evaluation]

Summarizes the Performance Improvement International (PII) investigation of the 12/28/98 blackout in San Francisco: “In summary, the blackout even was initiated by two human errors and was aggravated by multiple errors (some of them were latent errors) after initiation. The two errors which caused the event were: (1) omission of removing protective grounds and (2) omission of restoring a disabled relay that would have prevented the fault from becoming damaged.”

Refers to Integrated Vulnerability Analysis (see Figure A) to identify problems in which two independent human errors are involved, which PPI claims occurs most often as the source of unwanted events in non-routine situations (citing TMI, Bhopal, Challenger, Chernobyl, Valdez). Uses a matrix to propose improvements in work practice, equipment/design, work process, and management system for the three phases of event initiation, consequence containment, and recovery.

Clarke, D. M. & Wimpenny, B. (1995) “Human error data collection.” *IEEE Power Division Colloquium on the Role of the Operator in the Safety of the Nuclear Industry*, 5-1–5-3.

[Evaluation, Database]

Proposes simulators as a reasonable approach to collecting data for HEPs. Notes that error reports in actual operation may sometimes be useful for deriving HEPs, but a better approach to avoid reporting uncertainty is to use data loggers with plant simulators.

Clarke, L. *Barriers to Knowing Risk*. Department of Sociology, Rutgers University.

[Evaluation, Human Error]

Attributions of human error are preferred to shift blame, generally by upper management pointing down the organizational ladder. Suggests work is needed to understand the cognitive barriers to thinking usefully about risk, including in the area of public risk perception, e.g., how we understand systems, how production pressures affect managerial risk perception and vary with organizational form, how to face worst-case scenarios, how to consider the population of possible failures, and how to deal with questions of risk acceptability.

Cojazzi, G. & Pinola, L. (1996) “Root Cause Analysis Methodologies: Trends and Needs.” *Proceedings of the Human Factors and Ergonomics Society 40th Annual Meeting*.

[Modeling]

The technological advances in managing complex plants, by means of more and more powerful control and protection systems, has shifted the active role of the operator toward a supervisory task. In order to introduce changes in the design of the socio-technical system capable of preventing the occurrence of future accidents, a “detailed” analysis of actual accidental/incidental sequences represents the primary source of information. In this paper, the basic needs for a tool aiming at the assessment of the causes of human errors are presented and discussed with reference to the current existing tools and methodologies. Also, the needs for a root cause analysis (RCA) of human erroneous actions are discussed with reference to existing methods and theories. As a result of the discussion, a framework for RCA is proposed.

The Institute of Nuclear Power Plant Operations (INPO, 1988) has promoted a Human Performance Evaluation System (HPES) that has been largely adopted by U.S. utilities as a method for the assessment of human performances. The IAEA ASSET service (IAEA, 1991) concentrates on hardware and software ameliorations on the basis of an assessment of plant operational performance involving plant anomalies and incidents/accidents. RCA methodologies are conceived for the retrospective analysis of the accidental sequence to analyze system failures and the involved human actions in order to identify which ones involved errors and why, i.e., the root causes.

Colas, A. (1998) “Human performance in EDF.” *Revue Generale Nucleaire International Edition*, A, 27-31.

[Evaluation, Performance]

At the time when nuclear utilities were applying the lessons and human performance programs that followed Three Mile Island, EDF started up about 50 reactors in a 10-year span, with major changes in staffing and in technology. The paper notes that most of EDF’s emphasis has been on using measures external to the individual (organization, rules, orders, quality assurance, procedures, interfaces), “whereas most weaknesses remaining today are the result of personal or collective work methods and precautions.” Need to find ways to get the individuals to ask questions for a climate of change and for enhanced personal involvement with determination for safety. Current human performance work involves introspective analysis of practices and methods of functioning of the operational work teams, getting participation of managers, getting workers involved (to identify weak points, choose and implement solutions), and monitoring and determining responsibility within team.

Collopy, M. T. & Waters, R. M. (1996) “Human error root cause analysis.” *Proceedings of the Human Factors and Ergonomics Society 40th Annual Meeting*, 1272.

[Modeling]

This poster describes development of HERCA, an adaptation of the NRC’s Human Performance Investigative Process to DOE. Given a human performance deficiency, HERCA is used to develop a decision tree that directs the user to one of the eight major human error root cause categories.

Committee on the Safety of Nuclear Installations. (2000) “Identification and assessment of organisational factors related to the safety of NPPs: State-of-the-art report.” Nuclear Energy Agency, NEA/CSNI/R(99)21/Vol 1. (http://www.oecdnea.org/html/nsd/docs/1999/csni-r99-21-vol1.pdf)

[Safety]

Report based on a 1998 workshop sponsored by the Organisation for Economic Co-operation and Development. Participants from regulatory bodies, utilities, and research institutes discussed organizational factors related to nuclear power plant safety. They reached consensus on 12 major factors regarded as important for safety (listed below). Definitions are provided for each factor, along with examples. There is also a discussion of current research, and the report ends with a call for further research.

Major factors for safety:

1. External influences (from outside the boundary of an organization)

2. Goals and strategies

3. Management functions and overview

4. Resource allocation

5. Human resources management

6. Training

7. Coordination of work

8. Organizational knowledge

9. Proceduralization

10. Organizational culture

11. Organizational learning

12. Communication

Committee on the Safety of Nuclear Installations. (2000) "Identification and assessment of organisational factors related to the safety of NPPs: Contributions from participants and member countries." Nuclear Energy Agency, NEA/CSNI/R(99)21/Vol 2. (http://www.oecdnea.org/html/nsd/docs/1999/csni-r99-21-vol2.pdf)

[Safety]

Describes individual contributions to the workshop (see description of Volume 1 above).

Connelly, E. M., Van Hemel, S. B. & Haas, P. M. (1990) *Industry based performance indicators for nuclear power plants*. NUREG/CR-5568, Vol. 1. McLean, VA: Communications Technology Applications, Inc.

[Evaluation, Safety]

Describes phase one of a study to develop leading indicators for nuclear power plant safety, based on experience from other industries. From a review, the chemical/petrochemical manufacturing industry was chosen for further study. The proposed set of direct safety indicators included significant incidents, reportable incidents, precursor incidents, equipment forced downtime, safety system actuations, safety system unavailability, and unrelated uncontained releases (expressed as rates such as incidents/year, incidents/man-year, and incidents/safety device). Four program elements were chosen as a framework for indirect safety indicators: management of change in process technology, operating procedures, training, and mechanical integrity. Some candidate indicators reportedly were developed, but only a few examples are given in the report, e.g., actual vs. requested training budget; documentation of verification for equipment integrity; evidence of effective implementation of changes; and documentation of monitoring and evaluation for equipment integrity.

Converse, S. A. (1994) “Operating procedures: Do they reduce operator errors?” *Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting*, 205-209.

[Human Error, Evaluation]

Subjects (licensed reactor operators) performed an accident scenario and a change of power with a reactor simulator, requiring use of procedures available either on paper or in a computerized system. Media did not significantly affect performance measures on the nonstressful change of power task, although operators rated their performance more highly with the computerized procedures. For the accident scenario, subjects were faster with the paper procedures.

Conway, F.T. (1998) “The Influence of Job Factors in the Introduction of Rest Breaks for Intensive Data Entry Work.” *Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting*.

[Performance, Evaluation]

The study examined the relationships that psychosocial factors of work, psychological state, and personal factors had on musculoskeletal discomfort for intensive data entry work. Factors were measured at two locations that were implementing a new rest break schedule. This schedule provided hourly 5-minute breaks, in addition to two midshift breaks and a lunch break. Results indicated that psychological aspects of work were more of an indirect influence on discomfort.

Cooley, S.H. (1997) “Been There, Done That.” IEEE Sixth Annual Human Factors Meeting.

[Performance]

Describes experience of Stephen Cooley, a consultant working at Commonwealth Edison Company in Maryland. He has worked on many projects to contribute to improved station and personnel performance, as well as on control room and interface design in the nuclear industry.

Cooper, S.E., Bley, D.C. & Parry, G.W. (1996) “Knowledge-Base for the New Human Reliability Analysis Method, ‘A Technique for Human Error Analysis’ (ATHEANA).” *Proceedings from PSA '96, International Topical Meeting on Probabilistic Safety Assessment: Moving Toward Risk-Based Regulation*.

[Modeling]

Describes knowledge base to be used for ATHEANA (HRA, as introduced in NUREG/CR-6350). ATHEANA assumes “that operators behave rationally and perform very reliably except under certain combinations of plant conditions (typically unusual or unfamiliar accident conditions) and PSFs that virtually guarantee operator failure (i.e., error-forcing contexts).” Emphasis is placed on errors of commission involving flaws in cognitive

activities, and on identifying the likelihood of error-forcing contexts. Most of the discussion proceeds from behavioral science considerations and from analysis of five operational events.

Coovert, R.D., Smit, J.R., & ComEd Station B. (1999) "Team Errors/Social Loafing." 5th Annual Human Performance/Root Cause/Trending Workshop.

[Performance, Evaluation]

Authors, from ComEd Braidwood, suggest that configuration control issues tend to involve two or more people and can be linked to social loafing, i.e., the lack-of-responsibility problems that can arise in teams; variations include pilot/copilot (unwillingness to challenge the lead worker), dropping guard (placing too much confidence in the quality of others' work), free riding (reduced personal contribution), group think (striving for unanimity), and risky shift (greater risk taking in groups). At Braidwood, they explained these types of social loafing to workers, increasing awareness in hopes of improving performance.

Corcoran, W.R. (1999) "The Case of the Runaway Filter." 5th Annual Human Performance/Root Cause/ Trending Workshop.

[Modeling]

This paper provides an example application of runaway filter using Partial Phoenix Analysis (comparative timeline, missed opportunity matrix, why staircase dendograms, causal influence matrix, and safety break tailboard discussion topics).

Corcoran, W.R. & Davis, S.M. "Organizational Improvements from disasters; Effective Tools for Identifying Programmatic and Cultural Weaknesses." Nuclear Safety Review Concepts Corp.

[Evaluation, Performance]

Describes three tools for investigator to evaluate human and organizational performance related to an event or series of similar events. Tools are described below:

- Comparative TimeLine: list time, what happened, what should have happened, immediate result, and significance for final consequence. This is said to make it easier to explain investigative conclusions and to develop focused, cost-effective corrective actions.
- Missed Opportunity Matrix: columns for who (each person or group who could have done something), situation (time at which they could have done something), opportunity, expected result, and impact on consequences. The matrix is developed from interviews and brainstorming with the affected groups. This is said to be an "effective tool for communicating organizational and cultural weaknesses to management."
- Collective Significance Analysis: "Analysis collectively of the significance of a group of events or phenomena that seem to have more than one attribute in common," undertaken as self-assessment. Typical activities are divided by levels (individual and work group; management and supervision; independent assessment; external assessment) and by phase (routine; pre-emptive; reactive; periodic). "A Collective Significance Analysis is only called for when an aggregation of similar items induces the suspicion that

organizational learning from the individual occurrences is not serving the best interests of the organization or the public."

Corcoran, W.R. & Evans, R.W. (1997) "The Comparative TimeLine Highlighting Human Performance Factors." IEEE Sixth Annual Human Factors Meeting.

[Performance]

More detail on constructing the "Comparative TimeLine" described above.

Corcoran, W.R., Lengyel, G.J. & Pedersen, A. (1999) "The Thirteen Steps of a World Class Corrective Action Program." *Nuclear Safety Review Concepts*.

[Evaluation, Methodology]

Suggests steps that can be used to assess or structure a corrective action program: calibrate the people, identify the issues, characterize the issues, evaluate the issues, generate and select corrective actions, implement corrective actions, monitor and adjust corrective actions, trend the reliable data, learn from events, improve the processes, integrate the gains, publicize experience and results, and celebrate the journey.

Corker, K.M. (1998) "Cognitive Performance for Multiple Operators in Complex Dynamic Airspace Systems: Computational Representation and Empirical Analyses." *Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting*.

[Modeling]

This paper presents a set of studies in full-mission simulation and in the development of a predictive computational model of human performance in control of complex airspace operations. The model's predictive accuracy was verified using the full-mission simulation data of commercial flight deck operations with advanced air traffic management techniques. The paper reports focused analyses and empirical studies to predict the consequences of the interaction between these advanced automation technologies and the human component in the ATM system. "We have confidence that the Man-Machine Interactive Design and Analysis System (MIDAS) model predicts operational behavior at a course level of aircraft control. We have yet to explore the validation of the micromanagement of behavior and the contribution of individual behavior segments to the overall behavior observed. We have not yet validated the process of mutual expectation between air and ground-based control authorities and have not explored off-nominal operations in simulation."

Croll, P.R., Chambers, C. & Bowell, M. (1997) *A Study of Incidents Involving Electrical/Electronic/Programmable Electronic Safety-Related Systems*. GAAG Technical Report 97-2.

[Evaluation, Human Error]

Describes a review of 21 incidents involving programmable electronic safety-related systems in small manufacturing enterprises in the UK. Incidents were categorized into faults involving requirements, hardware, software, system use, maintenance, and environment, with sub-classifications as well. Nearly all incidents were assigned several causes. The most commonly identified faults were at the requirements stage—deficiencies in the safety requirements (system design); 17% involved failures to follow correct or safe operating procedures.

Dahlgren, K. & Olson, J. (1994) "Organizational Factors and Nuclear Power Plant Safety: A Process Oriented Approach." *Proceedings of PSAM - II*.

[Methodology, Evaluation]

Paper from SKI, the Swedish nuclear power inspectorate, emphasizes need for proactive as well as reactive approaches to improvement for fostering learning organizations or continuous improvement (said to be an important element in the success of Japan's economic growth including its nuclear industry). Continuously improving organizations are said to be characterized by goal-directed activity, strategies and planning, taking responsibility, using analysis, and participatory structures. No data are provided in the paper.

David, H. (1999) "Measuring human behavior in large groups - A review of methods and techniques." Eurocontrol.

[Methodology, Evaluation]

In the context of air traffic control operations, the author's team considered 35 different methods of measuring human behavior (e.g., debriefing, sleep logs, heart rate) from various types (subjective, physiology/electrophysiology, observation) and rated them on a series of criteria (e.g., duration of measure, portability, observer effects, ethical problems). Highest recommendations are given to a collection of subjective measures, plus operational records of system activity.

Davoudian, K., Wu, J-S. & Apostolakis, G. (1994) "The Work Process Analysis Model (WPAM): An Integrated Approach to the Incorporation of Organizational Performance into Probabilistic Safety Assessment Methodology." *Proceedings of PSAM – II*, 80-7 to 80-13.

[Modeling]

Industrial experience and research findings have shown that major concerns regarding the safety of nuclear power plants (NPPs) and other complex industrial systems are less about the breakdown of hardware components or isolated operator errors than about the insidious and accumulated failures occurring within the organizational and management domains. WPAM is developed to capture the common-cause effect of organizational factors on parameters such as equipment failure rates. It demonstrates the ways in which organizational factors are viewed to impact NPP safety.

Decision Systems, Inc. "REASON® Root Cause Analysis Process." www.rootcause.com.

[Modeling]

Described as root cause analysis software, including an expert system to guide the analysis by providing a tree model, cause-effect narrative, graphics, etc. Said to be used for nuclear plants, railroads, utilities, national laboratories, electronic manufacturers, chemical companies, and oil refineries. Demos and tutorials can be downloaded. The company also developed a lessons-learned report for Los Alamos National Laboratory. The company describes problems with typical lessons-learned activities (e.g., too much data, hard to search and use), and suggests that reports gathered systematically (e.g., with REASON) would yield a more effective relational database system for lessons learned.

Derocher, R. (1998) "All together Now, Teamwork creates a positive safety culture." *Safety & Health Management*, vol. 158, No. 2.

[Safety]

The stated goal of ConAgra and OSHA: lofty Voluntary Protection Program status for nine plants within 5 years, which would single them out as safety leaders. Lockheed Martin's Ocean, Radar and Sensor Systems apply a team approach. Solid waste services department.

Desaulniers, D.R. (1997) "Stress in the Control Room: Effects and Solutions." IEEE Sixth Annual Human Factors Meeting.

[Evaluation, Performance]

Stressful situations occur whenever there is a substantial imbalance, either real or perceived, between the demands of a situation and an individual's ability to handle those demands. Specific impairments of operator performance are identified in the paper. Current intervention strategies and emerging challenges for stress management in nuclear plant operations are discussed.

In reference to effects of stress, four general types of impairments in cognitive performance were identified: (1) narrowing and shift in focus of attention, (2) reduced working memory capacity, (3) time pressure effects, and (4) impaired crew communication patterns. There are numerous generic programs and techniques for stress management. Current practice to eliminate stress or minimize its effects on the performance of nuclear power plant operators involves methods that are most typically thought of as stress management. They include simulator training, communications and team skills training, procedure design, and examination process and methods.

New challenges exist in dealing with stress in the control room. Recent developments in control room technology are likely to have important implications for operator stress and performance during plant events. Severe accident management has also been an area of considerable focus. U.S. facilities are currently implementing programs to enhance their severe accident management capabilities. The potential effects of severe accident conditions on operator stress and performance were the subject of a study described in NUREG/CR-6211, which identified several training approaches for mitigating the effects of stress on the operator's cognitive skills. These approaches include (1) training techniques that make personnel more efficient information processors and reduce the demands on attention and working memory, (2) training to enhance crew coordination and communications skills, and (3) training using realistic severe accident simulations to reduce the novelty of severe accident conditions. The last recommendation was made recognizing that current simulation models generally do not support the simulation of severe accident conditions, and that NRC does not require such capabilities at U.S. facilities.

Dhillon, B.S. (1986) *Human Reliability with Human Factors*. Pergamon Press.

[Modeling]

Provides text/review, including HRAs; simple overview rather than in-depth coverage.

Diaz, R. I. & Cabrera, D. D. (1997) “Safety climate and attitude as evaluation measures of organizational safety.” *Accident Analysis and Prevention*, 29 (5), 643-650.

[Evaluation, Safety]

After noting the many previous recognitions of the importance of safety climate, such as Zohar (1980), the authors propose to study safety attitudes. In the study, 166 workers from three companies at a Spanish airport completed questionnaires aimed at safety climate and their safety attitudes; in addition, 29 experts in ground-handling activities answered questions about the safety level of the three companies involved. The results identified 6 factors in safety climate. Overall, safety, climate, and attitude scores for the three companies were said to be related (with some notable exception). There were also significant relationships between the scores and age, time in the company, and type of work.

Diaz, Y. F. & Resnick, M. L. (2000) “A model to predict compliance with employee corporate safety regulations factoring risk perception.” *Proceedings of the IEA 2000/HFES 2000 Congress*, 4, 323-326.

[Evaluation, Safety]

Survey results from 140 employees at a lighting manufacturing facility were compared with unobtrusive observations (five per participant) of usage of required personal protective equipment. “Workers with a history of workplace injury were more likely to comply with PPE requirements,” and “workers who perceived that company management care about their safety were more likely to comply.” Those who had low scores on a risk-taking personality inventory scale were also more likely to comply.

Donelson, A., Menich, R. P., Ray, R. M. & McCarthy, R. L. (1994) "Statistical analysis of vehicle rollover: Causal modeling." *Proceedings of the 38th Conference of the Association for the Advancement of Automotive Medicine*, 269-294, Lyon, France, September.

[Modeling]

Describes regression analyses applied to motor vehicle rollover accidents, comparing influence of various environmental, vehicle, and driver characteristics.

Donelson, A., Ramachandran, K. & Davis, M. S. (1996) "Vehicle rollover: Assessing the importance of risk factors with crash scenario analysis." In *Safety Engineering and Risk Analysis (SERA)*, F. J. Mintz (Ed.), SERA-Vol. 6, 7-14, American Society of Mechanical Engineers, New York, NY.

[Evaluation]

Describes development and application of a new method for studying accident sets. Statistical analyses identify common accident scenarios (where a scenario is defined by values of accident factors such as driver age or roadway location). Likelihood of a serious injury outcome is found to be highly related to driver characteristics.

Dorel, M. (1996) "Human failure in the control of nuclear power stations: Temporal logic of occurrence and alternating work times." In *Human Factors in Nuclear Safety*, N. Stanton (Ed.), Bristol, PA: Taylor & Francis.

[Human Error, Evaluation]

Starts by noting that the Chernobyl malfunction began at 12:20 a.m. Reports were examined for 110 human failure incidents at three French nuclear power plants. Incidents were nearly twice as frequent during the night as in the afternoon shift; the morning shift had almost as many as the night; for morning and afternoon, incidents are more frequent in the first and last part than in the middle of a shift. Notes that one must compromise between varying shifts to ease the burden of night shifts across workers and avoiding disturbances of shift cycles.

Dorner, Dietrich (1996) *The Logic of Failure*, NY: Henry Holt and Co.

[Evaluation, Performance]

Book describes work on the psychology of complex problem solving and the cognitive traps that often interfere. Describes simulation studies in which subjects try to manage a hypothetical country and fall prey to overgrazing, poor resource management, and other disasters; compares these to accidents such as Chernobyl insofar as having complex dynamic systems that the people involved do not understand well. The inability to see and know directly what is needed is called intransparence (e.g., not being able to see where the control rods are, rather having to rely on indicators). People form mental models and simplifications, and are then reluctant to question their assumptions. This suggests that people are unable to manage effectively when systems are complex and not transparent (so that the manager

cannot see the workings of all parts). Simulations (with people trying to manage artificial or hypothetical systems) show that people often make false assumptions about the systems, failing to understand the internal dynamics. Much of the book involves elucidating some of the drivers and consequences of mismanagement of complex systems.

Drury, C. G., Wenner, C. L. & Murthy, M. (1997) “A proactive error reduction system.” http://galaxyatl.com/hfami/mtng11/mt11_p12.htm.

[Modeling]

Review of aircraft maintenance errors from ground damage incidents, paperwork errors, on-the-job injuries, rework situations, late finds, and others suggested a relatively small set of common root causes that represent natural targets for intervention. Airlines have many error-tracking systems, and personnel can identify error-prone situations, but they need help in making changes to prevent repeated errors. PERS (Proactive Error Reduction System) “is essentially a database of solutions which have been shown to successfully address problems in the airline maintenance system.” PERS is intended to have an error reporting/tracking function, a means of predicting future errors, and a way to find solutions. A Unified Error Reporting System, developed in paper form for a previous project, is supposed to be computerized for PERS. The authors have not had much success gathering detailed records of solutions from the airlines. Airlines are using wide-scale, general approaches such as Maintenance Resource Management, Task Analytic Training, and Total Quality Management, but are not documenting solutions to specific problems. “It is important the solutions in the PERS database reflect more than obvious solutions to known problems. ... The collection of solutions to populate the database is on-going, and it is envisioned that this will in fact be a continuous process.”

To develop PERS, causal trees were developed for latent and active failures based on contributing factors from MEDA, performance shaping factors from human reliability analysis in the nuclear industry, causal error taxonomies, and other sources; trees were developed for management/supervision, communication, equipment/tools/parts, environment, and knowledge/skills/training. Solutions are tagged to points on the trees. Gateways are available for interfacing (eventually) with existing error reporting systems such as MEDA and MESH.

Drury, C.G. “Reducing Maintenance Documentation Errors.”

[Evaluation, Performance]

There is a measured clear need for better documents. Poor design causes errors. Many different interventions have been developed to improve documents. Each intervention must measure performance to show improvement. Usable documentation design aids are needed. Industry is beginning to use better design, getting less errors.

Dusic, M. (1997a) “Safety issues for digital upgrades in operating NPPs.” *Proceedings of the 1997 IEEE Sixth Conference on Human Factors and Power Plants*, 4-1–4-6.

[Evaluation, Methodology]

As NPP control rooms move from analog to digital safety and control systems, concern must be given to a single-failure criterion (that no single failure should lead to an event), common mode failures, environmental reliability, and the human-machine interface.

Dusic, M. (1997b) “ASCOT - Guidelines for self-assessment of safety culture.” *Proceedings of the 1997 IEEE Sixth Conference on Human Factors and Power Plants*, 6-14–6-17.

[Evaluation, Safety]

ASCOT (Assessment of Safety Culture in Organizations Team) Guidelines are used for self-assessment of safety culture, such as attitudes, morale, motivation, and commitment to safety; the guidelines address government organizations, the corporate level, the plant level, and support organizations. ASCOT is offered through the IAEA (International Atomic Energy Agency, Austria), based on INSAG-4.

Eckenrode, R.J. (undated) “NRC Monitoring of Human Performance Trending Using the Human Factors Information System.”

[Evaluation, Performance]

Describes HFIS, the seven human performance categories (communications; human-system interface and environment; management and supervision; organizational issues; procedures and reference documents; training; work factors), and data sources (Licensee Event Reports [LERs], NRC Inspection Reports [IRs], NRC Licensed Operator Examination Reports [ERs]). Procedures and Work Factors are most common in LERs, while Work Factors are most common in IRs; other breakdowns are provided. HFIS is hoped to be useful for industry-wide issue trending and comparative analyses. HFIS coding scheme is available at www.nrc.gov/NRR/HFIS/codescm1.html.

Eckenrode, R.J. & West, G., Jr. (1997) “Detailed Control Room Design Reviews: Were They Worth The Effort?” IEEE Sixth Annual Human Factors Meeting.

[Control Room]

Timeline of steps and NUREGs in the process of detailed control room design reviews from TMI-2 to completion.

Edkins, G. D. (1998) "The INDICATE safety program: evaluation of a method to proactively improve airline safety performance." *Safety Science*, 30, 275-295.

[Evaluation, Safety]

Describes a proactive safety management program for an Australian airline: Identifying Needed Defences in the Civil Aviation Transport Environment (INDICATE). Says methods such as MESH and REVIEW, based on Reason's work, rely too much on subjective attitude measurement scales and their focus on identifying potential latent failures (in organization, workplace, and person/team levels), which are difficult to identify. Instead, for INDICATE, emphasis was placed on determining the integrity of safety defenses (engineered safety devices; policies, standards, controls; procedures, instructions, supervision; training, briefing, drills; personal protective equipment). Identifying an inadequate defense in turn reveals latent failures in the decisions or conditions influencing that defense. Elements of INDICATE involve 6 core safety activities: an operational safety manager; staff focus groups to identify safety hazards (using Delphi technique); confidential safety hazard reporting system; safety meetings with management; safety information database; and regular distribution of safety information to staff.

The program was implemented at one regional center for the airline, using another center as a control (except that both had a confidential safety hazard reporting system). The treatment group showed a significant improvement in scores on the Airline Safety Culture Index (safety culture), significant improvement on perceived hazardousness and perceived likelihood (ratings for a list of 22 common safety hazards found in an aircraft accident classification system), and an increase in the number of safety hazard forms submitted, as compared with the control group. In addition, a number of safety issues were brought to attention and dealt with in the control site. Author concludes that INDICATE had a positive influence on safety management, resulted in action on hazards and a positive safety partnership, and showed the benefit of a structured framework to encourage communication within the organization. Furthermore, it was felt that the safety culture measure appeared to be a useful indicator of effectiveness, consistent with previous results (Zohar, 1980; Bailey & Peterson, 1989; Dedobbeleer et al., 1990), as well as with findings of high accident rates with poor safety culture scores (Glennon, 1982; Guest et al., 1994; Hidden, 1989). Notes that research on the relation between risk perception and actual incident or accident frequencies has mixed results, and that further work is needed in aviation.

Edmondson, A. C. (1997) "Learning from error in teams: The role of face to face work groups in preventing incidents and accidents." M.I.T. Conference on Organizational Processes in High Hazard Industries, http://stsfac.mit.edu/projects/risk/reports/intro.html.

[Evaluation, Human Error]

Notes that there are at three different approaches in the literature to understanding errors and accidents, focused on individuals, systems, and work groups. Notes that teams can act as self-correcting performance units, and that there has been research on what makes some teams function well.

Embrey, D. E. (1992) "Quantitative and qualitative prediction of human error in safety assessments." *Symposium on major hazards onshore and offshore*, 329-341.

[Modeling]

Notes there are many uncertainties in the quantitative data for human error probability estimation, but that the major benefits are the qualitative insights with regard to sources of risk and priorities for intervention efforts. Describes SPEAR (System for Predictive Error Analysis and Reduction), which is designed for looking for active, latent, or recovery errors in normal operations, abnormal/emergency operations, maintenance, or plant changes. An analyst considers the risk potential of each of these for a given potential hazard; any human errors identified in this way are selected for further qualitative consideration, using techniques of task analysis, performance-influencing factor analysis, screening analysis, predictive human error analysis, consequence analysis, and error reduction analysis (all briefly described and illustrated in the paper).

Endsley, M. R., Onal, E. & Kaber, D. B. (1997) "The impact of intermediate levels of automation on situation awareness and performance in dynamic control systems."

[Evaluation, Performance]

Automation can create out-of-loop problems to produce a loss of situation awareness; it has been proposed that intermediate levels of automation may be optimal for minimizing the negative impacts of loss of situation awareness. A study of performance in a simulator (for tele-operation of a robot for manipulating plutonium pit storage barrels) found faster processing with higher automation but also greater time to recover from an automation failure.

EPRI. (1988) *Control-room deficiencies, remedial options, and human factors research needs*. EPRI NP-5795.

[Evaluation, Human Error]

The author, Seminara, obtained 25 Detailed Control Room Design Review (DCRDR) reports, which nuclear power plants were required to produce (NUREG-0737, Supplement 1). Human engineering deficiencies (HEDs, collapsed from the NUREG-0700 criteria into 114 categories) were tabulated and rated in importance. The number of HEDs per report was found to increase over the time period reviewed (1981-1986). Most common categories were displays, followed by workspace, labels, controls, and enunciators. Based on this work, a literature review, and an industry review conference meeting, a list of 28 research candidate topics was generated. These were rated by the members of the industry review panel.

EPRI. (1994) *Wrong Unit, Train, and Component Events at U. S. Nuclear Power Plants: Joint EPRI-CRIEPI Human Factors Studies*. Palo Alto, CA, TR-103954.

[Evaluation, Human Error]

Describes work by Eldridge and Seminara. Deals with human-related errors in which personnel work on the wrong unit, attempt to use the wrong train of equipment, or operate the wrong component. Characteristics and causes of a set of 505 such events were determined by investigating the events and coding on such dimensions as activity during event, equipment involved, and personnel involved. Cognitive error was determined to make up a larger portion of events since recommendations were made and implemented (NUREG-1192), whereas inadequate design, training, and labeling made up smaller portions than before. Labeling efforts had been aimed at labeling items throughout the plants; it is noted that informal labels had become rare, although it is sometimes a battle to prevent personnel from creating their own labels. It was felt that labeling, coding, and bar coding had been successful. Other efforts discussed include formal verification, self-verification (teaching personnel to, e.g., stop-think-act-review or stop-think-observe-perform), training, procedure improvement, disciplinary action programs, improvement of working conditions, and various operator aids.

EPRI. (1997) *An Input-Training Neural Network Approach for Gross Error Detection and Sensor Replacement*. EPRI TR-107875.

[Modeling]

Describes work by Reddy and Mavrovouniotis. Compares principal component analysis (PCA), partial least-square regression, and neural network techniques for process monitoring. Data were taken from 65 temperature sensors in a system of four heaters in an electric power plant; the observed dimensionality of 65 was reduced to 44 by preprocessing (replacing variables with strong linear correlation by their first principal component score). The input-trained net was found to be more effective than linear PCA for detecting, identifying, and rectifying gross errors, as well as for sensor replacement tasks.

EPRI. (1999a) *Pilot Study: Occupational Health and Safety Surveillance Database*. Palo Alto, CA. TR–113884.

[Safety, Databases]

Feasibility study for collecting and analyzing health and safety data from electric utilities. Describes initial data from several participating utilities, along with the types of findings that may be useful if industry-wide comparisons can be made.

EPRI. (1999b) *Guidelines for Leading Indicators of Human Performance: Preliminary Guidance for Use of Workplace and Analytical Indicators of Human Performance*. EPRI TR-107315.

[Evaluation, Human Error]

Summarizes work to date by Wreathall, along with Reason and Hanes, to identify promising leading indicators. A survey of nuclear and other industries found very little evidence of use of leading indicators, except for some worker surveys, trending of small consequence human errors, and deviations from performance goals and targets. PAOWF (Proactive Assessment of Organizational and Workplace Factors), a survey tool, is described: ratings of 12-20 statements are collected from plant workers and supervisors, using a software tool, similar to the previous MESH and Review tools for British Rail. A literature review led to identification of seven recurring themes related to safety from organizational performance models: top-level commitment, awareness, preparedness, flexibility, just culture, learning culture, and opacity.

EPRI. (2000a) *Occupational Health & Safety Annual Report 2000: Injury and Illness in the Electric Energy Workforce, 1995-1999*. Palo Alto, CA. 1000740.

[Safety, Databases]

EPRI has established an ongoing health and safety database that is designed to provide more precise and detailed information about workplace injury and illness occurrence. It incorporates health and safety, workers' compensation, and personnel data provided by energy companies. The project team applied standardized coding and classification procedures to make these data comparable across the different companies. They integrated 5 years (1995-1999) of personnel, injury, and claims data into a single data system summarizing injury trends by company, occupation, injury type, and demographic factors (age and gender). The database now covers approximately 135,000 employee-years.

The database provides the capability for epidemiological monitoring, annual injury/illness reporting, program evaluation, and occupational health and injury research. This report presents the first annual set of injury trends analyses.

EPRI. (2000b) *Guidelines for Trial Use of Leading Indicators of Human Performance: The Human Performance Assistance Package*. Palo Alto, CA. 1000647.

[Performance]

EPRI Nuclear report based on review of organizational behavior models for the selection of possible leading indicators in nuclear power settings.

EPRI. (2001a) *The Real Challenge of Safe Behavior: Transitioning From Being Accountable to Feeling Responsible,* Palo Alto, CA: 1004667.

[Performance, Safety]

Report sponsored by Strategic Human Performance Program that describes approach used by Geller in setting up behavioral safety programs in industrial organizations.

EPRI. (2001b) *Predictive Validity of Leading Indicators: Human Performance Measures and Organizational Health*. Palo Alto, CA. 1004670.

[Evaluation, Human Error]

A set of candidate leading indicators of human performance was developed by comparing organizational health themes with data available at a nuclear power plant (the themes were developed in the course of a work sponsored by the EPRI Nuclear Human Performance Technology program [EPRI, 1999b; Wreathall & Jones, 2000]). Based on 5 years of operational data, statistical analyses were performed to search for relationships between the candidate indicators and various plant outcome measures selected for use in the study. Several promising connections were found, including a significant difference in certain indicators leading up to two scheduled outages. The period prior to "poor" outage performance was characterized by significantly higher backlogs (e.g., temporary modifications, corrective maintenance, technical staff requests, engineering work requests) and fewer dollars spent on training. The period leading up to a successful outage was notable for the significantly reduced backlogs, the higher ratio of preventive to corrective maintenance, and a higher number of rework orders initiated, all of which may indicate increased vigilance. In addition to these findings, conclusions were drawn regarding the requirements and limitations of data analysis in a field as new as this. Many of these lessons have received further support from the ongoing strategic project (EPRI, 2002).

EPRI. (2001c) *Collecting and Using Near-Miss Information: Enhancing Switching Safety and Reliability*. Palo Alto, CA. 1001956.

[Evaluation, Human Error]

Describes results from a survey of 9 energy companies concerning their collection and use of information regarding near-miss incidents. Sites were found to differ in the details collected, the use of incentives for reporting, the procedures used for investigation of reported near-miss incidents, and the organizational reactions. There is no discussion or analysis of the incidents themselves in this report.

EPRI and U.S. Department of Energy. (2001d) *An Integrated Framework for Performance Improvement: Managing Organizational Factors*. Palo Alto, CA. 1003034.

[Evaluation, Performance, Safety]

Report from EPRI's Nuclear sector providing a review of human performance improvement tools that are intended to address organizational factors. The report relies on industry models of organizational change. A framework is proposed for selection of performance improvement tools.

EPRI. (2002) *Organizational Epidemiology: Analytical Approaches for Predicting Human and Energy Facility Performance.* Palo Alto, CA. www.epri.com.

[Evaluation, Human Error]

Describes progress in EPRI strategic "Human Performance Management: Database and Analysis" project focused on applying "organizational epidemiology" to improve understanding of how worker-, workplace-, management-, and organization-centered factors may affect human and facility performance. Various statistical and analytical techniques are being used to explore potential predictive relationships among types of data that address a variety of error-, facility-, worker-, work/task-, and management/organization-related factors. In work to date on data collected from two participating fossil-fired steam-electric plants, several statistically significant predictive relationships have been identified. In addition, insights have been gained on data availability and collection, analytical techniques, and human performance factors. Final report scheduled to be issued by late 2002 as EPRI report 1004669.

Feher, M. P. (1997) "Detailed control room design reviews - Were they worth the effort?" *Proceedings of the 1997 IEEE Sixth Conference on Human Factors and Power Plants*, 3-22 – 3-26.

[Evaluation, Human Error]

Drawbacks with the Canadian experience with detailed control room design reviews include the following: lack of explained basis or rationale for some human engineering discrepancies (HEDs) can lead to misinterpretations of guidelines; function and task analyses were not linked to the rest of the guidance; no guidance was given as to what to do with the large number of HEDs; and no higher-level framework was given to allow the checklist to be interpreted within context.

Fenstermacher, T. E., & Kopecek, J. T. (1994) "The Use of Risk Contours to Clarify Risk Communication." *Proceedings of PSAM - II*.

[Risk]

This paper discusses risk contours, including what they are, how to determine them, and how to use them to clarify risk communication. Risk contours provide a useful way to look at the

risk from a plant or operation. When planning the layout of a new plant, a set of risk contour maps allows the responsible engineers to determine a layout that minimizes the risk impact of the plant. When a change in the plant operations is planned, risk contours can show the change in the risk, whether positive or negative, in the vicinity of the plant.

Risk contours are a graphical tool for presenting the results of a risk analysis. They are produced by combining the results of the risk analysis, including the consequence analysis, with historical data on the local meteorology. The resulting risk contour map shows the distribution of risk both at the plant site and in the surrounding area. Risk contour maps can be used to present information to engineers, local licensing and emergency planning officials, and members of the general public who are concerned about the plant. Care must be taken to assure that the target audience is familiar with the terms that are used to describe the risk contour levels.

Fischer, S. C. & Blowers, P. A. (1995) "A behavioral sequence model analysis of human error with infusion pumps." *Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting*, 964.

[Human Error, Modeling]

This abstract describes work at Anacapa Sciences regarding infusion pump errors. The Behavioral Sequence Model was applied to data from FDA databases and from task analyses and interviews of 14 nurses.

Fitts, P. M. & Jones, R. E. (1947) *Analysis of factors contributing to 460 'pilot-error' experiences in operating aircraft controls*. Memorandum Report TSEAA-694-12, Aero Medical Laboratory, Air Materiel Command, Wright-Patterson Air Force Base.

[Performance, Evaluation]

A set of control-operation error reports, provided by witnesses or the persons involved, was reviewed. They could be categorized as errors of substitution, adjustment, forgetting, reversal, unintentional activation, or inability to reach, with further subcategories. The most common category was substitution, involved in 50% of the errors; it is suggested that redesign of controls can reduce these errors. Practically all pilots contacted, regardless of training and experience, reported sometimes making errors in the use of cockpit controls.

Ford, J.K., Kozlowski, S.W.J., Kraiger, K., Salas, E., & Teachout, M.S. (1997) *Improving Training Effectiveness in Work Organizations*. Mahwah, NJ: Lawrence Erlbaum Associates.

[Evaluation, Performance]

A collection of papers that grew from a conference on training effectiveness at Michigan State University. One paper (Rogers *et al*.) discusses applications of cognitive task analysis, including automatization of skills, and declarative vs. procedural knowledge in CAPTAM (Controlled and Automatic Processing Task Analytic Methodology). Another (Goldsmith & Kraiger) discusses techniques for assessing workers' structural knowledge as a basis of

planning training (rather than for eliciting the knowledge itself). Several papers address the role of organizational context in training.

Forsythe, C. & Wenner, C. (2000) "Surety of human elements of high consequence systems: An organic model," *Proceedings of the IEA 2000/HFES 2000 Congress*, 3-839-842.

[Modeling]

Surety was developed in the context of nuclear weapons to ensure very low probability of catastrophic failure, especially where it is impossible or impractical to characterize all potential failure paths. Systems involving people can be viewed as organic, thus exhibiting characteristics of living things (organization, homeostasis, sensitivity, metabolism, reproduction, growth/development, adaptation). "The Organic Model offers an alternative perspective that provides insight into the sources of human variability."

Forzano, P. & Castagna, P. (1997) "Procedures, quality, standards, and the role of human factors and computerized tools." IEEE Sixth Annual Human Factors Meeting.

[Evaluation, Performance]

Discusses the role that human factors can play with respect to some basic factors related to power plant procedure management. Operating Procedures and related specific aspects like knowledge representation, formal aspects, Human-Machine interface, and procedure life cycle management have been deeply investigated in ANSALDO. Based on these experiences, ANSALDO presents a proposal to overcome current lacks in the procedural world: a computerized system named DIAM. DIAM is an attempt to offer a tool for procedure management, inspired by practical day-by-day issues. It embeds drawing and documentation standards. It offers some new features like automatic flow diagramming and the structuring of large diagrams into pages, the congruence of step names and line paths, and the automatic printout of the procedure book.

Freudenburg, W. R. (1992) "Nothing Recedes Like success? Risk Analysis and the Organizational Amplification of Risks." *Risk Issues in Health & Safety*, 3(1), Winter 1992.

[Risk]

Urges inclusion of social science contributions in risk assessment. Notes that risk level (as well as risk perception) can be influenced by organizational factors, such as commitment to risk management, ease of information flow, diffusion of responsibility, and risk-taking for perceived corporate goals. Also warns of the atrophy of vigilance, especially for rare or unexpected problems; causes include complacency and boredom, the nonproductive status of safety measures (no immediate benefits), and displacement of goals (focus on resources expended rather than the safety results achieved). Anecdotal examples from well-known accidents are cited.

Freudenburg, W. R. (1997) “Dealing with those pesky, low-probability disasters: A reaction to papers for the M.I.T. Workshop on High-hazard Production Systems.” M.I.T. Conference on Organizational Processes in High Hazard Industries

[Risk]

High-probability risks lead to accumulation of experience; conversely, with very low-probability risks, atrophy of vigilance sets in, i.e., complacency. Organizations tend to focus on core tasks. Individuals are subject to boredom and lack of vigilance; safety measures are nonproductive (as long as the risks are rare enough) and may not survive budget-cut pressures. In the aftermath of an accident, vigilance increases, safety efforts increase; then things slowly slide back. Organizations can become “systematically stupid,” using the “disqualification heuristic,” ignoring contradictions to safety, developing shared perspectives, and placing emphasis on secrecy. As an antidote, the author points to the beneficial effects of increased permeability of an organization’s outer boundaries, which not only improves community relations but also improves safety. No data are presented; the author argues by example.

Friedlander, M. A. & Evans, S. A. (1997) “Influence of organizational culture on human error.” *Proceedings of the 1997 IEEE Sixth Conference on Human Factors and Power Plants*, 12-19 – 12-22.

[Evaluation, Performance]

Cites demonstrations that organizations, including electric utilities, have improved operational and financial results by having the right corporate culture or undertaking strategic culture change. Describes work for Pennsylvania Power & Light related to corporate culture and human error. Organizational culture can motivate employees in various ways, related to work unit inter-relationships, trust, communication, leadership, management focus, attitudes towards confrontation, and teamwork. For this study, “cultural values deemed critical to the performance of the department were empirically determined in 16 separate areas” using a survey of employees during five consecutive quarters; human error data were categorized as people-people, people-management systems, people-organizational structure, and people-technology. It is reported that error scores were correlated with corresponding culture scores; additional data are being collected.

Fujimoto, H., Fukuda, M. & Tabata, H. (1994) “Sensitivity study of human errors as a basis for human error reductions on new safety system design.” *Reliability Engineering and System Safety*, 45 (1-2), 215-221.

[Evaluation, Modeling, Performance]

Notes that human errors can be categorized along a variety of dimensions, including timing, personnel, system, type of error, location, and operator experience. A PSA for a conventional PWR was reviewed with regard to the sensitivity for core damage frequency (CDF) based on HEPs. It was concluded that pre-accident human errors are relatively frequent compared to post-accident and recovery errors, but that post-accident errors have a larger impact on CDF and should receive more attention than they presently do.

Fujimoto, J. (1996) “Construction and Use of Human Factors Database System.” IERE Workshop, Human Factors in Nuclear Power Plants.

[Database, Evaluation]

Describes work at CRIEPI, where the human factors database consists of literature data, good practice data, questionnaire data, human error analysis data, and miscellany (safety posters, lessons learned, HF dictionary, and HEP data). Each of the more than 2,100 documents in the literature database is represented by an abstract, keywords, and category. Utilities that receive update lists can order documents of interest. The good practices are collected from power plants and sorted by 12 categories, including the following five for nuclear power: good practice for improving working environments, labeling and coding of plant instruments and equipment, fool-proof or fail-safe ways to prevent human error, caution reports, and WANO good practices. The event analysis database includes near-miss reports. No information is provided, however, about the number of reports included or the types of analyses conducted (although Excel and Lotus are mentioned). One chart shows a breakdown of near miss by worker age bracket and by type of event (omission errors, misreading and wrong choice, communication errors, misjudgment, operation errors, carelessness, and other); it appears that some categories (e.g., operation errors, misjudgment, misreading) decrease as a percentage of all events with increased age or experience, while others increase with age (carelessness, omissions).

Fujita, Y., Sakuda, H., Yanagisawa, I. (1994) “Human Reliability Analysis Using Simulated Human Model.” *Proceedings of PSAM - II*, 60-13 to 60-18.

[Modeling]

Describes a task analysis tool, CAMEO, that is based on a simple human information processing model (perception/recognition; decision making; action; attention resource control; long-term memory; working memory). Task simulation is said to reveal specific types of errors, such as in response to inadequate resources. The aim is to improve HRA.

Furuhama, Y., Furuta, K. & Kondo, S. (1995) “Identification of causes of human errors in support of the development of intelligent computer-assisted instruction systems for plant operator training.” *Reliability Engineering and System Safety*, 47 (2), 75-84.

[Safety]

Describes a system that uses predefined questions to learn why a trainee made specific errors during computer-assisted instruction.

Furuhama, Y., Furuta, K. & Kondo, S. (1994) “Causal Identification of Human errors toward Intelligent CAI System for Plant Operation.” *Proceedings PSAM - II*.

[Modeling, Evaluation]

This paper proposes a methodology for identifying causes of human errors in operation of plant systems; it is based on considering operator’s cognitive process on the assumption that the process can be modeled as means-end analysis. A prototype CAI system has been developed for training in plant operation procedures that has the capability of identifying causes of trainees’ errors based on the methodology.

Gaba, D. M. (1997) “Risk, regulation, litigation, and organization issues in safety in high-hazard industries.” M.I.T. Conference on Organizational Processes in High Hazard Industries, http://stsfac.mit.edu/projects/risk/reports/intro.html.

[Evaluation, Safety]

The author is an anesthesiologist studying organizational issues in health care. Notes Rasmussen’s description of safety as a “cyclical issue” (similar to Friedlander on the atrophy of vigilance), getting the most attention right after a catastrophe; low-frequency near misses or non-events that might signal declining safety may be explained away or rationalized, a phenomenon called the normalization of deviance. Refers to the normal accident concept (Perrow) that complex systems with tightly coupled components will always have accidents; Perrow suggested that nuclear power is intrinsically too dangerous. Conversely, LaPorte and others at Berkeley developed the High Reliability Organization theory, depending on priority of safety and reliability by leadership, high levels of redundancy, a high-reliability culture in decentralized and practiced operations, and sophisticated trial-and-error learning; similarly, Sagan described a culture of reliability within organizations. Military organizations can achieve a high degree of socialization; it is more difficult to create the same level of culture of reliability (or professionalism) in the commercial nuclear power industry, maritime transport, or health care, due in part to production pressures. Refers to the n-tuple bind or combination of pressures and goals in the work environment, as suggested by Cook and Woods. The idea that safety should outweigh all other factors is naive, and practitioners cannot always choose the safest path; “all large complex systems have intrinsic risks and hazards that must be incurred in order to perform their functions” (quoting Cook & Woods). Issues of regulation and litigation are discussed, as is the conflict between reporting and punishment. Raises general research issues, such as the extent to which hazardous industries are unaware of root causes versus unable to deal with them effectively because of n-tuple binds.

Gallman, J. (1998) “Managing Your Human Performance Program as if it Were Money.” TU Electric

[Evaluation, Performance]

Suggests diversifying the portfolio of human performance efforts to ensure sufficient independence and preclude common mode failures. Should include both reactive and proactive elements and should address individual, leader, and organizational levels.

Gallman, J. (1999) “Report on an IAEA Workshop on Applications of Selected Event Analysis Methodologies to Actual Events in Nuclear Power Plants,” Jan 25 - Feb 5.

[Evaluation, Modeling]

Lists advantages and disadvantages for event and causal factor charting, change analysis, barrier analysis, human performance evaluations, and MORT. Discussion of safety culture and common problems in nuclear plants.

Ganey, P. J. (1999) “Managing Resistance in Corrective Actions,” Fifth Annual Industry Workshop on Human Performance, Root Cause Analysis, and Trending, May.

[Evaluation, Modeling]

The question considered in this analysis is, “How does a root cause evaluator or evaluation team manage resistance to necessary corrective actions from senior management?” The answer is found through both internal and external analysis. Understanding resistance to ideas, the source of conflict, and methods to manage conflict is a key attribute of a learning organization and a critical competency for analysts involved in corrective action programs. The concept that conflict should be avoided is a major contributor to mechanistic stagnation, particularly in organizations where resource allocations are heavily contended, such as corrective action implementation. Understanding the source of organizational resistance provides the strategic impetus for overcoming that conflict. In order to be effective, analysts must ensure that conflict outcome is approached through systematic methodologies. Combining these skills reinforces an analyst’s position as a problem solver, and ensures that organizational resistance will result in positive outcomes.

Gayley, R. B. (1997) “Implementing NRC Regulation 10CFR50.65, The ‘Maintenance Rule’, Using An Expert Panel.” IEEE Sixth Annual Human Factors Meeting.

[Evaluation, Performance]

10CFR50.65, “Monitoring the Effectiveness of Maintenance at Nuclear Power Plants” (the “Maintenance Rule”), requires monitoring the performance of certain systems, structures, and components (SSCs) against licensee established goals (or performance criteria) to provide reasonable assurance that they are capable of performing their intended functions. A panel of individuals with expertise in specific areas can be used to perform a number of activities required by 10CFR50.65. This paper provides insights on the utilization of an

Expert Panel at the Quad Cities Nuclear Power Station. The expert panel requires expertise in each of the following areas: (1) plant operations and emergency operating procedures; (2) accident/transient assessments; (3) system engineering; and (4) Maintenance Rule requirements. The expert panel has the following responsibilities: (1) review and approve revisions to scooping data, (2) review and approve risk significance determination data, (3) review and approve revisions to SSC performance criteria, (4) review and approve proposed revisions to delete functions and remove associated data from the maintenance rule data, and (5) assist the Maintenance Rule owner in resolving questions about existing scoping, risk significance, and performance criteria data. Individual members of the Expert Panel have responsibilities to the panel consistent with their area of expertise.

Geller, E.S. (2000). "The Real Challenge of Behavioral Compliance: Transitioning From Being Accountable to Feeling Responsible," Prepared for EPRI, Palo Alto, CA.

[Performance]

Describes approach used in setting up behavioral safety programs in industrial organizations. Published by EPRI, 2001 (1004667).

Geller, E. S., Roberts, D. S. & Gilmore, M. R. (1996) "Predicting propensity to actively care for occupational safety." *Journal of Safety Research*, 27 (1), 1-8.

[Evaluation, Safety]

Behavioral feedback programs have been shown to have a beneficial effect on occupational safety, but they are hard to implement on a long-term basis unless the employees themselves become involved. Geller has suggested "actively caring," in which employees help others such as by giving constructive behavioral feedback; employees most likely to emit actively caring (AC) behaviors are presumed to have high self esteem, group cohesion, and optimism. Such employees, if identified, can be used to help sustain safety programs. Several previous studies are reported as having provided support to this concept. In the present study, questionnaires were completed by manufacturing workers; AC was predicted by reactance, extroversion, personal control, and group cohesion.

Gertman, D.I., Haney, L.N. & Ostrom, L.T. (1994) "Evidence of the Need to Model Errors of Commission in Risk Assessments for Varied Environments." *Proceedings of PSAM - II,* 5-15 to 5-20.

[Modeling]

Argues that cognitive errors of commission are underrepresented in PRA/HRAs. Uses cognitive event trees "to represent personnel's likely cognitive realm (skill, rule, or knowledge) and error mechanisms (slips, lapses, mistakes, and willful violations) involved in each of the errors of commission." Examples are provided, including ad hoc identification of PSFs.

Gibbs, S. & Adams, N. (1999) "Attitudes not processes as the arbiter of safety." *Proceedings of CybErg 1999: The Second International Cyberspace Conference on Ergonomics*, 312-320.

[Evaluation, Safety]

Cites Gibbs' dissertation (lit review, 382 interviews and site inspections at 143 different fieldwork locations), which claimed that "a series of negotiated compromises operated in all countries visited" with respect to handling of chemotherapy drugs in the health industry. In particular, safety issues were presented haphazardly in education, training in safety procedures was almost nonexistent for unskilled workers, inconvenient procedures were often neglected, cost-cutting was common, focusing on occupational health and safety was perceived as a weak career move, and "individual site variations were largely attributable to a particular workplace culture that in general devolved from senior management attitudes, example and the level (or lack) of on-going supervision and validation."

"In effect, the workplace cultures which produce the safety-oriented (or more correctly, the non-safety-oriented) practices and performances are a direct reflection of—and simultaneously reinforce—the underlying sets of individual attitudes identified in the research and emphasized in this discussion."

Gilbert, V. (1997) "NEI Benchmarking Process Evolution of Human Performance Indicators."

[Evaluation, Database]

The Benchmarking Process is intended to include identifying good practices, improving productivity and reducing cost, using performance measures, and developing continued improvement through process management. The Nuclear Integrated Information Database supports these efforts. Includes mention of various human performance PIs: LERs, human error/equipment problems, NRC Error Codes I and II, NRC Significant Events, various INPO PIs (SOERs, HPES, Excellence in Human Performance, Data Trending Model), NERC Error Codes, Culture Surveys, and others.

Goodman, C., West, G. Jr. & Schoenfeld, I. (1997) "Criteria for review of root-cause analysis programs." *Proceedings of the 1997 IEEE Sixth Conference on Human Factors and Power Plants*, 2-1 – 2-6.

[Evaluation, Modeling]

Describes NRC criteria for reviewing root-cause analysis programs and corrective action plans, as well as evaluation criteria for communications problems.

Goosens, L.H.J. & Glansdorp, C.G. (1994) "Accident Sequence Precursor Methodology for Maritime Safety." *Proceedings of PSAM - II*, 71-1 to 71-6.

[Evaluation, Modeling]

Describes work in the Netherlands, in which the Accident Sequence Precursor (ASP) methodology (from Oak Ridge) was applied to ship incident data. ASP was designed for situations with operating experience but not enough data to allow statistical predictions of serious accident probabilities; it involves the use of generic event trees and summation of conditional probabilities. A precursor is an initiating event or unavailability of a safety system. By examining the generic event trees, the importance of various precursors can be evaluated. It is reported that complex situations (in which the navigator is not able to assess the right set of observables) have much higher accident likelihood.

Graeber, R. C. & Marx, D. A. (1993) "Reducing human error in aircraft maintenance operations." Presented at the Flight Safety Foundation 46th Annual International Air Safety Seminar, 148-159.

[Evaluation, Modeling]

Cites Sears (1986) that maintenance and inspection were significant factors in 12% of major aircraft accidents reviewed; a more recent study by the authors finds that nearly 20% of commercial jet aircraft accidents could have been prevented by changes in the levels of maintenance and inspection. A major airline is described as having found that omissions accounted for 56% of maintenance errors (during 2 years of operation), compared with 30% for incorrect installation and 8% wrong parts; this is said to be consistent with a 1992 study from the UK. Maintenance errors are generally poorly understood because they may be discovered a long time after they take place; also, the search for a root cause and someone to blame discourages reporting and useful data. Mentions MEDA (Maintenance Error Decision Aid) as under development to assist event investigators in the analysis of human error.

Grabowski, M. & Roberts, K. (1997) "Risk mitigation in large scale systems." *California Management Review*, 39 (4), 152-162.

[Risk]

Discusses large-scale, human-machine systems, such as the U.S. marine industry. There is concern that managers do not understand large-scale systems well. Subsystems tend to be both autonomous and interdependent, making risk mitigation difficult. Risk mitigation measures can have unintended consequences, and problems can have long incubation periods; furthermore, risk can migrate in the system. Lessons learned from high-reliability organizations may be helpful: effective communication, consistency in beliefs, flexible organizational structures to deal with contingencies, and shared culture.

Green, M. M., Morisseau, D., Seim, L. A., & Skriver, J. (2000) "Development of an incident investigation process." *Proceedings of the IEA 2000/HFES 2000 Congress*, 4-388-390.

[Evaluation, Human Error, Performance]

In order to further reduce the role of human errors in incidents, improved incident investigation is needed. A preliminary study of 250 offshore oil incidents, using tools such as the Human Performance Investigation Process and the Maintenance Error Decision Aid, found that human error was often under-reported. The authors briefly describe Sequential Timed Events Plotting (STEP) as "a simple, structured approach to collecting and assembling incident data" using a time line and analyzing critical events. In addition, an investigation questionnaire is used to address performance-influencing factors in nine main categories (procedures, training, communication, human-machine interface, plant etc., work preparation/supervision, organizational/management, environmental, and work execution).

Gross, M., Ayres, T., Wreathall, J., Merritt, A. & Moloi, D. (2001) "Predicting human performance trends." *Proceedings of the 7th Annual Human Performance/ Root Cause /Trending Workshop*, Baltimore, MD.

[Evaluation, Safety]

Summary of interim findings from the literature and background review performed for the "Human Performance Management: Database and Analysis" project under EPRI's Strategic Human Performance Program. Discusses lessons learned from experiences in fossil generating plants, and compares and contrasts these lessons with EPRI strategic work performed at nuclear generating facilities (EPRI, 2001b).

Gross, M. M., Ayres, T. J. & Murray, J. (2000) "Analysis of human error at electric utilities." *Proceedings of the 44th Annual Meeting of the Human Factors and Ergonomics Society*, 3, 173-176.

[Evaluation, Human Error]

Summary of interim findings from the literature and background review performed for the "Human Performance Management: Database and Analysis" project under EPRI's Strategic Human Performance Program. Discusses conceptually related work in other process industries and describes the nature of types of underlying (background) data that are intrinsic to analyses of antecedent conditions.

Grote, G. & Kunzler, C. (1994) "Safety Culture and Its Reflections in Job and Organizational Design: Total Safety Management." *Proceedings of PSAM - II*, 47-7 to 47-12.

[Evaluation, Safety]

Safety culture was defined by the International Nuclear Safety Advisory Group (INSAG) as "that assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, nuclear safety issues receive the attention

warranted by their significance." Authors (who are from Swiss Federal Institute of Technology) argue that safety culture is not independent of technology and organization, but should be integrated as part of Total Safety Management, similar to Total Quality Management. In a sociotechnical systems approach, the technical and social subsystems need to be jointly optimized for maximum effectiveness. Preliminary results are presented from work at three chemical companies and one transportation company (interviews, questionnaires, observations, and document analyses). Safety is an integral part of the primary task in the transportation company but not in the chemical plants, which have traditionally been tied to production.

Gunnarsson, T. & Gustavsson, M. (1997) "Upgrading of Control Room in Oskarshamm 1." IEEE Sixth Annual Human Factors Meeting.

[Control Room]

Sydkraft, the second largest utility in Sweden, initiated a pre-study in 1994 with the aim to develop a control room philosophy as a basis for development and design of upgrading of control rooms for six different units. At present, all process control is hardwired and analog. The control rooms are mainly conventionally instrumented, with process computer systems as a complement for information presentation only. This paper presents a short overview of the control room philosophy, the design basis, and the first planning and development steps in realization of a control room modernization for Unit 1 at OKG AB.

Hackman, J. R. (1983) "The design of work teams."

[Evaluation, Modeling, Performance]

Begins with the notion that individual-, group-, and environment-level factors determine the group interaction process, which in turn determines output. Reviews research on group performance. A normative model for work groups in organizations posits that output is a function of the collective effort, the knowledge and skill, and the performance strategies used. Group effectiveness is affected by the design of the group, its organizational context, and the group synergy. Each of these is discussed, with suggestions for effective management.

Hahn, H. A., Auflick, J. L. & Morzinski, J.A. (1996) "Demonstration of a Prototype Knowledge-Base System for Estimating Human Error Probabilities." *Proceedings of the Human Factors and Ergonomics Society 40th Annual Meeting,* 869.

[Modeling]

This paper describes a prototype knowledge-based system (KBS) to help practitioners find appropriate human error probabilities for inclusion within probabilistic risk assessments and human reliability analyses, a collection of methodologies for "the analysis, prediction and evaluation of work-oriented human performance in quantitative terms." The system starts by asking users how much human factors and task analysis data is currently available:

"minimal" takes users to the HCR techniques, "moderate" leads to ASEP, and "extensive" will start the user down a THERP path.

Hale, A., Wilpert, B. & Freitag, M. (1997) *After the Event: From Accident to Organisational Learning*. New York: Pergamon.

[Evaluation, Methodology]

Presentations from a 1995 workshop sponsored by NeTWork (New Technologies and Work, from German and French organizations). Rosenthal's paper discusses the value of organizational epidemiology—linking databases to explore relationships between accidental chemical releases and the attributes of organizations and regulatory systems—but only as an idea. Most studies continue to rely solely on accident review, such as McDonald's treatment of a set of 921 aircraft ramp accidents.

Hallbert, B. P., Sebok, A., Morisseau, D. S. & Persensky, J. J. (1997) "The effects of advance plant design features and control room staffing on operator and plant performance." *Proceedings of the 1997 IEEE Sixth Conference on Human Factors and Power Plants*, 5-7 – 5-12.

[Evaluation, Performance]

Describes studies of control room simulator performance by 4-man (normal) teams and 2- to 3-man (minimum) teams of experienced operators. Subjective workload was rated higher by the smaller teams, and performance was somewhat poorer. Situational awareness was better with the larger team in a conventional plant but better with the smaller team in an advanced plant; similar findings were found for team interactions.

Hannaman, G. W. & Singh, A. (1994) "Human Reliability database for In-Plant Application of Industry Experience." *Proceedings of PSAM - II*, 12-1 to 12-6.

[Evaluation, Modeling, Database]

Describes an EPRI-financed project to provide plant users with lessons learned from events (see EPRI reports NP-6560, NP-6937, TR-100259). Classifications were developed to include human-system interactions, human errors, and human reliability shaping factors. LERs for less-than-full-power events were classified and integrated into the database, and software was developed (RECIPE - Reliability Enhancement through Classification of Industry and Plant Events) for use on PCs.

Harris, M.S. (1994) "The Significance of Operator Team Interaction Skills to Nuclear Power Plant Risk." *Proceedings of PSAM - II*, 33-1 to 33-6.

[Evaluation, Modeling]

Describes an NRC-sponsored project. Notes that large accidents (TMI, Chernobyl) tend to involve a combination of human and mechanical failures, including failure of crew members to provide adequate checks and balances for each other and to share doubts early. Necessary

team interaction skills include communications, feedback, effective influence, conflict resolution, and leadership. In this project, an analysis was made of the likely contribution of improvement in team interaction skills to potential reduction in core-melt frequency, using a PRA model. “It appears that for those plants whose current quality of team interaction skills is relatively poor, the potential reduction in public risk achievable by improving operator team interaction skills is quite large.”

Harrison, D. (1993) “A trending database for human performance events.” *Proceedings of the Sixteenth Reactor Operations International Topical Meeting*, 265-268.

[Modeling]

Describes plans for a computer database system based on INPO’s HPES (Human Performance Enhancement System) for the research facilities at Chalk River Laboratories (two research reactors in Ontario, Canada).

Hastings, K.B. (1997) “Maintenance Rule Supports Millstone Station’s Recovery Efforts.” IEEE Sixth Annual Human Factors Meeting.

[Evaluation, Performance]

Insights and improvements realized through implementing the Maintenance Rule at Millstone Station are presented. The system performance aspect of the paper focuses on the Maintenance Rule Goal Setting process with an emphasis on the performance issues related to human factors. The causes and corrective actions for unacceptable performance on selected Millstone Station systems are discussed.

Haugset, K. (1997) “Overview of Human-System Research at the OECD Halden Reactor Project.” IEEE Sixth Annual Human Factors Meeting.

[Evaluation, Human Error]

The OECD Halden Reactor Project is an international nuclear research program operated by the Institute for Energy Technology (IFE), Norway, since 1958. Countries in Europe, America, and Asia participate. The research program consists of two major parts: (1) fuel and materials research performed in the Halden Boiling Water Reactor, and (2) human-machine studies for improvement of operational safety and efficiency.

The latter research activity is experimentally oriented. Research topics include human error analysis, human-centered automation, and development and evaluation of computerized operator support systems and control room concepts. The main tool is the Halden Man-Machine Laboratory, with the HAMMLAB control room coupled to a simulator of a nuclear plant.

The NORS full-scope PWR simulator, based upon the Loviisa nuclear power plant in Finland, is the nucleus of HAMMLAB. A substantial extension of HAMMLAB will take place in the period 1997-1999. HAMMLAB will be extended with a simulator of the oil and gas production process. The program includes four main areas: software verification and validation, man-machine interaction research, computerized operator support systems, and control room development.

He, Wei G. (1994) "Assessing Organizational Impact on Reactor Safety." *Proceedings of PSAM - II*.

[Evaluation, Safety]

Notes that "hundreds of organizational factors that are potentially related to reactor factors [that] impact nuclear safety have been proposed." This paper proposes a method based on PRAs to quantify the role of organizational factors, with core damage frequency (CDF) as the risk parameter. Logically, core damage frequencies are to be compared across similar nuclear power plants, and the inter-plant differences are to be attributed to plant practices related to organizational factors. Notes there are problems in comparability such as customized design and unique external environments. The method has been used with three NPPs (He's dissertation at MIT). Reportedly, it was found that the magnitude of organizational impact varied from 0.1 to 10, and that several organizational factors were found to contribute to CDF, including activity ownership, line of communication, and "maintenance crew and operator training." Notes that "the determination of organizational factors responsible for the CDF deviation can be difficult since the search is an inductive process."

Hedge, A., (1998) "Quantifying Office Productivity: An Ergonomic Framework." *Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting*.

[Performance, Evaluation]

An ergonomic framework is described for conceptualizing and measuring office productivity. This framework is based on the analysis of task time, posture and sequence, and the subsequent determination of the most appropriate pace, posture, and activities for any office job. The framework assesses various measures of pace, proficiency, and posture that currently can be readily assessed by ergonomists, and it uses these measures to quantify the short-term duty cycle productivity and the longer-term life-cycle productivity of office workers.

Helmreich, R. L. & Merritt, A. C. (1998) *Culture at Work in Aviation and Medicine: National, Organizational and Professional Influences*. Ashgate: Aldershot, UK.

[Evaluation, Performance]

Reviews variations in culture and their apparent relations to safety and performance in two contexts: aviation, principally cockpit; and medicine, principally anesthesia. Professional culture tends to smooth out national differences (e.g., some tendency for commonality among commercial pilots everywhere). Notes that professional culture in these occupations is subject to both selection and self-selection of participants, with perhaps some restriction on personality types who become involved.

Several survey studies have found differences in national culture among employees around the world, along such dimensions as Power Distance, Individualism-Collectivism, Uncertainty Avoidance, and Masculinity-Femininity (Hofstede). In addition to affecting behavior, such cultural differences can have additional influence when members of differing cultures work together, such as when a captain from a high power distance culture has a subordinate from a low power distance culture. Follow-up study by the authors failed to closely replicate the country differences found by Hofstede. Notes that accident rate differences between countries cannot be attributed directly to culture differences, because the infrastructure, resources, and other factors are likely to differ as well.

Also discusses methodological approaches to cultural response biases. Organizational culture is locally determined (within an organization) and therefore is easier to both study and change. Schein (1996) makes a simple distinction between the organizational subcultures of operators, engineers, and executives; interactions can be problematic. Notes that the tone of management memos and press releases can reflect (and may also affect the perception of) the degree to which management values the internal efforts of workers versus the economy and the bottom line. It is assumed that the organizational climate affects safety, but the authors mention there is no empirical evidence. The alleged characteristics of a “safety culture” are discussed, such as open communication. Five principles are proposed for error management: recognizing that human error is inevitable, that there are limitations on human performance, that errors occur when performance limits are exceeded, that safety is a universal value, and that high-risk organizations have a responsibility to maintain a safety culture. The strengths and historic evolution of CRM are discussed, along with evaluations of its effectiveness. Data are essential for diagnosing the organizational culture; accident and incident reports are primarily for reactive data (although incidents, etc., can be treated as proactive), whereas proactive information is obtained from surveys, systematic observations (including line audits), and some performance measures such as flight data recorders. Notes that examination of ASRS (Aviation Safety Reporting System) data has shown that language barriers are frequently cited when U.S. crews fly in other countries.

Herrin, J. L. (1997) “Duke Power Company's detailed control room design review.” *Proceedings of the 1997 IEEE Sixth Conference on Human Factors and Power Plants,* 3-27 – 3-28.

[Evaluation, Performance]

Among the conclusions: few significant events based on human error have occurred in Duke’s control rooms since completion of modifications to correct the HEDs (human engineering deficiencies), although human factors problems have occurred in other areas of the plant.

Heyes, A. G. (1995) “PRA in the nuclear sector - Quantifying human error and human malice.” *Energy Policy*, 23 (12), 1027-1034.

[Risk]

Discusses difficulties and problems for probabilistic risk analysis in the nuclear industry. Notes that some accident sequences may not be adequately considered, such as the various effects of earthquakes (e.g., relay chatter leading to loss of power), and that it is very difficult to estimate the probability of terrorist sabotage. Mentions a 1985 INPO estimate that 65% of nuclear system failures involve human error and 51% are caused by human error (no citation). Cites Cave (1988) that PRA outcomes for a given plant can differ widely, depending on the credit given to reactor personnel for their ability to take recovery action under pressure. Notes that the tremendous complexity of nuclear power plant PRAs effectively obscures the regulatory enforcement process from outside scrutiny.

Hibit, R. & Marx, D. A. (1994) "Reducing human error in aircraft maintenance operations with the Maintenance Error Decision Aid (MEDA)." *Proceedings of the Human Factors and Ergonomics Society 38th Annual Meeting*, 111-114.

[Modeling]

Notes that the first-level maintenance manager or lead technician is not only the person most responsible for managing error, but also the person with the least control over many of the contributing factors such as design, work cards, or shift turnover procedures. Cites the ICAO accident investigation model, based on Reason's work. MEDA was designed with the idea that "human errors are seldom random and can be traced to causes and contributing factors which, once isolated, can perhaps be eliminated or at least reduced." MEDA was designed in conjunction with Boeing, the FAA, British Airways, Continental, and United. Organizational analysis involves a significant operational event and tends to involve the technician, supervision, the airline's quality assurance and engineering organization, the manufacturer, and the FAA. Local factors analysis, on the other hand, typically involves only the technician and an immediate supervisor to deal with an error that is caught locally. The Investigation Results Form is used to assist the investigator in capturing information about the event. The contributing factors checklist is based on SHEL and involves either procedure/task information, equipment/tools/parts, environment, communication, or individual. The corrective action portion provides options to assist in error management. A field test was planned.

Higgins, J.C. & O'Hara, J.M. (1994) "Risk Management Activities to Address the Impact of Human errors and Human Error Variability." *Proceedings of PSAM - II*, 12-5 to 12-12.

[Risk]

This paper examines various aspects of risk-significant human actions or errors identified in PSAs, such as uncertainty, variability, importance ranking, and risk sensitivity. This paper also addresses risk management activities associated with human actions, both PSA-based and otherwise, and how these risk management activities may affect PSA error modeling. Values for both uncertainty and variability were determined and utilized in BNL studies on the sensitivity of risk to human errors. The four uncertainty factors were combined to derive a composite uncertainty error factor (the factor by which the mean HEP may be increased or decreased). Once the important human actions (or classes of actions) have been identified, there are many ways to address them from a risk management standpoint. These risk management activities can be categorized into the following groups: actions based on PSA insights, corrective and preventive actions for actual occurrences, and other preventive activities. By taking a broad-based approach of the techniques mentioned, a facility could reduce the overall sensitivity of risk to human error.

Higgins, J.C., & Pope, N. (1997) “Human Factors Aspects of the Major Upgrade to the Control Systems at the LANL Plutonium Facility.” IEEE Sixth Annual Human Factors Meeting.

[Control Room, Modeling]

The Facility Control System (FCS) monitors, displays, alarms, and provides some limited control of several systems. This paper discusses the human factors aspects of the design, installation, and testing of the FCS at the Plutonium Facility (TA-55) at Los Alamos National Laboratory. The Human Factors Engineering (HFE) Program Review Model was used to provide guidance and a structure to the design and test portions of the project. This model’s purpose was to provide guidance on evaluating a Human-System Interface (or control room) design and implementation process that includes the HFE program elements required to develop an acceptable detailed design and to ensure that the final design is appropriately supported.

Hoffman, M. S. (1998) “Influence of Organizational Culture in Europe on Perceptions of the Role of POS Technology in the Store.” Proceedings of the Human Factors and Ergonomics society 42nd Annual Meeting.

[Performance, Evaluation]

Macroeconomic studies with two large European supermarket companies in Germany and Italy were completed. These studies included in-store observations, transaction processing measurement, associate and store management focus groups, and corporate management interviews. The store analyses revealed that organizational communication, social traditions, ergonomic standards, and legal restrictions were perceived barriers preventing the use of new technology to transform their business.

Hollnagel, E. (1993) *Human Reliability Analysis, Context and Control*. Academic Press.

[Modeling]

Hollnagel prefers the label erroneous action, defined as “any action which fails to produce the expected result and which therefore leads to an unwanted consequence,” over human error, which can denote either the type of action or its cause. Most of the book is concerned with a critical examination of past work on human reliability analysis. In its place, he advocates modeling of cognition, using what he calls contextual control models.

Hollnagel, E. & Cacciabue, P.C. (1994) “Reliability of Cognition, Context and Data For a Second Generation HRA.” *Proceedings of PSAM - II*, 60-1 to 60-6.

[Evaluation, Modeling]

This work focuses on context, and on the two ways in which the context interacts with the human, i.e., in terms of "the environment affecting the human" and of "the human response to control the environment." The inclusion of the effects of the context in existing methods of

HRA is possible, and it would already grant a considerable progress towards the formulation of more complex and complete techniques.

The consideration for the context is the first crucial step towards the formulation of really innovative methods. However, the second fundamental and necessary step forward consists in coupling the contextual effects with the actual dynamics of the interaction between the system and the human in control. In this way, the overall simulation scenario is completed, as all the actors of the interactive loop, namely the humans and the machines, are simulated in parallel and in consideration of their mutual effects for the complete study of the safety of a system. The accomplishment of this second development is also being studied and will be the object of the future research. Finally, it can be argued that the improvement of the "classical" HRA techniques can be performed in a stepwise process aiming at new approaches, which are more complete, both for the consideration for the actual context and for the inclusion of the dynamic characteristics.

Hollnagel, E., Mancini, G., & Woods, D.D. (1988) *Cognitive Engineering in Complex Dynamic Worlds*. San Diego: Academic Press.

[Evaluation, Human Error]

Collection of papers that grew from a 1986 workshop. Reason suggests that failures in complex systems often arise from the combination of trivial failures, pointing to resident pathogens and making it difficult to provide easy fixes through operator support. Wagenaar & Groeneweg review 100 maritime accidents and reach the related conclusion that errors are generally not recognized until they combine and lead to an accident; therefore efforts to prevent accidents cannot rely on just increasing people's vigilance. Muir argues that decision support systems have to be trusted by the human operators in order to be properly utilized. Rizzo *et al*. describe studies of the various psychological mechanisms involved in catching one's own errors.

Howard, R. A. (1990) "From Influence to Relevance to Knowledge." *Influence diagrams, Belief Nets and Decision Analysis*, 3-23.

[Evaluation]

Provides formalization of some aspects of influence diagrams, described as "the most effective tool available for the representation and evaluation of decision problems."

Hoyos, C. G. & Zimolong, B. (1988) *Occupational Safety and Accident Prevention*. New York: Elsevier.

[Safety]

Concerned primarily with injury, and a system safety approach. Summarizes analytical frameworks for accident analysis into systems theory (e.g., Hammer), sequential models (e.g., Heinrich; Swain), integrative models (e.g., deviation or perturbation concept), and epidemiology (e.g., Haddon). Examples are given of studies involving either accident reviews or worker surveys (but not both). One study found that workers were not accurate at judging which occupations were more risky, but they had a good sense of which workplaces were most likely to contain risk of falling.

Hsueh, K. S., Soth, L. & Mosleh, A. (1994) "A Simulation Study of Errors of Commission in Nuclear Accidents." *Proceedings of PSAM - II*, 66-1 to 66-6.

[Modeling]

The purpose of the study is to develop a modeling methodology for errors of commission focusing on abnormal situations in nuclear power plants (NPPs), a very constrained environment in which interactions are primarily guided by written or memorized procedures. Specifically, the development of a realistic human model, which addresses errors of commission in the post-trip operator actions, is the subject of this paper. To demonstrate the proposed methodology, steam generator tube rupture and loss of heat sink (LOHS) events are analyzed using a simulation-based accident analyzer (ADS).

In summary, this paper proposes a cognitive approach in characterizing operator actions as procedure-following with various ways of deviation, and in classifying human decision-making mechanisms and influencing factors. To demonstrate the feasibility of proposed approach and to test the role of various cognitive factors, the proposed model is implemented in a dynamic simulation environment. Key human cognitive factors are delineated and traced in terms of operator mental state including operator diagnosis state, emergency procedure state, stress factor, and action index. The Westinghouse symptom-based procedures and a Westinghouse plant have been chosen for the case study.

The simulation results show that shortcuts and omission errors, although they can occur relatively more frequently, have minor impacts on the nuclear safety. This is because that the structure of EOPs comprises of several redundant steps and the diagnosis strategy. The effect of operator stress only has minor impact on the overall results. The study shows the continuous monitoring of critical function tree dictated in the EOPs is a very effective way to prevent human errors. However, the study is limited to slow transients only.

For the cases such as large LOCAs, human error rates can be much higher. In the case of LOHS, the delayed action due to perceived consequences has been found to be the dominant contributor to core deterioration. The current EOPs use the accident symptoms as the cue for diagnosis. However, throughout the whole procedures, there are no redundant steps or instructions to handle false signals and instrument failures. This error mode that is embedded in the process of reasoning has been found the dominant contributor to the core melt. It is not unusual that plant operators often misuse "rules of thumb" even with missing, contradictory, of defective grounds.

In conclusion, a methodology has been presented that provides a systematic framework for analyzing and implementing operator errors during NPP accidents. EOPs and intentional deviations from EOPs form the basis for defining operator actions. Major performance-shaping factors as well as the inference rules are also discussed in this paper. In order to support this new expanded realm, a simulation-based model, ADS, is used to implement the proposed operator model.

Hutchins, S. G. & Westra, D. P. (1995) “Patterns of errors shown by experienced Navy combat information center teams.” *Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting*, 454-458.

[Modeling]

A study was conducted using a Navy cruiser combat information center simulator. The TapRoot® Incident Investigation System, originally applied in production facilities such as NPPs, was modified and applied to the study results.

International Civil Aviation Organization. (1993) “Investigation of Human Factors in Accidents and Incidents.” ICAO Circular, 240-AN/144, Human Factors Digest No. 7.

[Evaluation, Modeling]

International Civil Aviation Organization (ICAO) is headquartered in Montreal. This document, which complements the ICAO Manual of Aircraft Accident Investigation, is basically a how-to manual for investigators. Uses Reason's categories of decision makers, line management, preconditions, productive activities, and defenses, as well as the distinction between active and latent failures and the swiss cheese model; the SHEL model is also used as a framework for factors to investigate. Advocates collecting investigation reports in a database; for ICAO contracting states, ADREP is the principle database used (but "unfortunately, to date ADREP has not been consistently used to record pertinent data from incidents or even from some State's accidents"). Provides a human factors checklist with various behavioral, medical, operational, task-related, equipment design, environmental, information transfer, other personnel, and survivability factors, to be rated as 0-3 (not/possibly or probably contributory/evidence of hazard). There is also an extended checklist based on SHEL, and a checklist for selecting, training, and experience.

INPO. (1990) “Increasing personnel awareness of frequent causes of human performance problems.” INPO 90-001, Good Practice OE-906.

[Modeling, Evaluation]

Describes seminars to present root cause analysis, based on HPES. Notes that "human performance problems are evident in approximately one-half of the events that occur within the nuclear industry. These problems are the result of factors that can be managed if systematically identified and corrected."

Iridiastadi, H. (1998) “Measurement of Ergonomic Program in a Workplace: A Proposed Framework.” *Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting*.

[Evaluation]

This paper discusses several financial measurements that can be used to justify expenses associated with ergonomic interventions. This paper also introduces the use of balanced measures. This approach takes into account nonfinancial and indirect performance resulting from ergonomic interventions in a workplace. In addition, this paper proposes the concept of Ergonomic Performance Index (EPI), an aggregated figure that tells management the magnitude of performance improvements achieved within a specified time frame.

Isoda, H. & Yasutake, Y. (1992) “Human factors interventions to reduce human errors and improve productivity in maintenance tasks.” *Proceedings of ANP'92, the International Conference on Design and Safety of Advanced Nuclear Power Plants*, 3, 34.4-1 to 34.4-6.

[Human Error]

Describes a joint project between CRIEPI (Japan) and EPRI; aim was to identify critical maintenance tasks that are error prone or have high potential for productivity improvement, to specify interventions, and to evaluate and develop guidelines for reducing errors and improving productivity in maintenance. Several interventions are discussed.

Jacobsson, L. & Svenson, O. (1994) “Self-Reported Human Errors in Control Room Work.” *Proceedings of PSAM - II*, 26-1 to 26-8.

[Evaluation, Human Error]

Nuclear control room operators were asked to record their errors using a questionnaire and a diary. The questionnaire asked for errors to be described as mistakes (misinterpretations), slips (inattention, or forgetting essential information), or violations (had to deviate from procedure). All four types of errors were reported in both normal operation and outages, with errors reported more frequently during outages. Notes various potential problems with such self-report data, e.g., bias due to confounding with the reporter's own memory, lack of studies correlating subjective with objective error data, etc.

James, M. R. (1998) “The Corruption of a Measurement System Due to Unintentional Bias: A Preliminary Macro-Ergonomic Study.” *Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting*.

[Evaluation, Performance]

This study examines the reaction of humans to external prompts in a measurement setting. In a measurement system, indications about the expected outcome of inspections can lead people to inadvertently change their measurement techniques, such that their results are significantly skewed toward the bias value compared to an unprompted group. In two of the four measurement tasks in the rigid mechanical system, the evidence supported the hypothesis that a bias can be introduced. In the visual inspection system, each of the two measurement tasks supported the existence of an unintentional measurement bias. This study presents a challenge to the objectivity of measurement systems, which is generally accepted, and poses several research questions from which future studies can be spawned.

The findings are a concern to researchers and practitioners. Based on the evidence presented by this initial test of the Pygmalion Defect Theory, it appears as if the Pygmalion Defect does not exist in some measurement systems. Real-world measurement/inspection systems should be impacted by the knowledge that this phenomenon can occur in realistic measurement systems. Thus, managers interested in objective measurements should be provoked to take more precautions against influencing a worker's measurement behavior.

Jeffroy, F. (1997) "From Safety Assessment to Research in the Domain of Human Factors: the Case of Operation with Computerised Procedures." IEEE Sixth Annual Human Factors Meetings.

[Evaluation, Safety]

This paper looks at the notion of safety assessment supporting research as developed by the Institute of Nuclear Safety and Protection in the human factor domain. First, it lists the main issues identified when assessing the safety of computerized procedures from the human factor point of view. This paper also presents the methodology used to gather and analyze data in an attempt to delve further into these issues by means of research.

The Electricite de France (EDF) project to design a new computerized control room for the future N4 nuclear series emerged in the early 1980s. The N4 series control room is highly computerized. From the outset of the project to design a computerized control room, EDF offered to use tests on simulators to prove safety from the human factor angle. From 1987-1989, EDF continued designing the control room, and carried out almost 200 tests on simulators. On the basis of these results, some of the initial characteristics of the control room were modified. This specific field of safety assessment supporting research requires the people who carried out the safety assessments to be directly involved. It also requires the research units to be involved in specifying and dealing with these issues, in order to take a step back from directly operational problems.

Jentsch, F., Barnett, J., Bowers, C. A. & Salas, E. (1999) "Who is flying this plane anyway? What mishaps tell us about crew member role assignment and air crew situation awareness." *Human Factors*, 41 (1), 1-14.

[Evaluation]

The hypothesis: when an aircraft captain is the person flying a plane at a given moment, he/she has a double burden because of also having to make decisions based on information from other members of the crew; by reducing situational awareness (SA), this double burden could increase accident risk.

The study: 221 incident reports from the ARS that were found to provide clear information as to who was in control at the time were coded (e.g., error type, primary error category, loss of SA). It was found that loss of SA was coded for 52.8% of incidents with the captain flying the plane, vs. only 40.5% when the first officer was flying ($p < 0.10$ one-tailed). Other analyses examined role of aircraft size, phase of flight, weather conditions, etc. The captain was more likely to lose SA when acting as the person flying the aircraft than when the first officer was flying, contradicting the notion that active involvement in controlling the plane helps one maintain SA. 20% of the cases involved lack of assertiveness by the first officer. It is noted that the airplane cockpit environment is unusual in that the team leader (captain) is also often doing active process control; this is not the case in many other industries and

situations where a boat captain, power plant shift supervisor, or air traffic control supervisor plays a more executive function and leaves the details of control to other team members or subordinates.

Jurow, D. (1998) “Build management teams with the power to lead.” *Power,* 142 (2).

[Methodology]

Describes efforts at South Texas Project (STP) and PG&E's Diablo Canyon to apply team management skills. "Managers at these plants have been transformed into effective leaders, individual contributors, and members of high-performing teams." STP used facilitative leadership; the change began with workshops for senior managers, then cascading training through the organization. Line managers were used to deliver the training because of their credibility with the workforce. Movement of the plant from the NRC watch list to high ratings is attributed to these changes.

Kalinowski, A. M., Lau, E. C., Butler, W. J., McCarthy, R. L. & Ray, R. M. (1992). “Statistical analysis of observational data: A study of ATV-related injuries.” Presented to the Winter Annual Meeting of the American Society of Mechanical Engineers, Anaheim, Paper 92-WA/SAF-8.

[Database]

Statistical analyses of population-based surveys of all-terrain vehicle (ATV) use and associated injuries are presented to illustrate some of the factors that complicate analysis and interpretation of observational data. These analyses show how conclusions regarding ATV safety can be affected by the choice of the data, the statistical model, and the model specifications. The relationships between engineering considerations and the results from statistical analyses, as well as the implications of the use of the statistical models for policy decisions, are discussed.

Kaplan, M. (1995) “The culture at work: cultural ergonomics.” *Ergonomics*, 38 (3), 606-615.

[Evaluation, Safety]

Concerned with influences of national culture on work, as presumably reflected in differing accident rates, e.g., crew-factor accident rates in the aircraft industry are much higher in some parts of the world than in others. Cautions that techniques such as Crew Resource Management may not be easily transferable across cultural boundaries without appropriate adaptation. [This article does not deal with the "safety culture" within a workplace or organization.]

Kasperson, R. (1999) “Industrial Restructuring and Effects on Corporate Risk Management.” *CHPCS Sixth Annual Workshop Proceedings, Human Performance: Bridging the Gap Between Research and Practice*.

[Methodology]

There are many impacts of downsizing on the health and safety management systems. Staff shortages can lead to stress and task overloads and under-qualified staff. It can change employee attitudes and risk, and a reduced staff interaction contributes to industrial accidents. Less safety training for contract workers and language barriers can also result. Downsizing can also cause disproportionate reductions in EHS expertise and capabilities and loss of institutional memory. Restructuring outcomes for corporate risk management are many: (1) increased reliance on unskilled and poorly motivated contract workers, (2) reluctance to supervise contractors so as to avoid certain legal liabilities, (3) management inattention to safety systems during organizational changes, (4) loss of organizational expertise and memory, (5) problems in fitting new information systems to corporate staff culture, and (6) inadequate screening and monitoring of contractor capabilities and performance.

Kawano, R. (1996) “Steps toward the realization of ‘human-centered systems’—An overview of the human factors activities at TEPCO.”

[Evaluation, Human Error]

A review of NPP accidents or problems found that each was characterized by a chain of events, background factors, the possibility of being prevented by cutting the chain, and prior similar events. Human factors are viewed in terms of an m-SHEL model: software, hardware, environment, liveware, and management factors. Several areas of research at TEPCO are described.

Kelly, J. (1998) “Human Factors.” Exxon Chemical Co.

[Evaluation, Safety]

Outlines Human Factors (HF) program at Exxon Chemical, including initiatives such as Safety Excellence Program and Total Safety Culture. Attributes reduction in total recordable incident rate from 1993-1996 to the HF initiatives.

Kelly, K. (1994) *Out of Control: The Rise of Neo-Biological Civilization*. Addison-Wesley. Excerpt (Cracking Wall Street) at http://www.cs.brown.edu/research/ai/dynamics/tutorial/Documents/CrackingWallStreet.html.

[Modeling]

Describes work of Doyne Farmer and others at Prediction Company, who are attempting to apply nonlinear dynamical modeling to finance and looking for pockets of predictability in the chaos of financial market data. Refers also to work by Andrew Colin with evolving

trading algorithms: the program randomly generates hundreds of hypotheses of which parameters influence currency data, then tests them against 5 years of data to find the best fits; then a neural net attempts to adjust the parameter weights.

Kirwan, B. (1995) “Current trends in human error analysis technique development.” In S. A. Robertson (Ed.), *Contemporary Ergonomics 1995,* Taylor & Francis: London, 111-116.

[Modeling]

In chapter, 35 HEI (Human Error Identification) techniques were reviewed with respect to their usefulness for risk assessment. Notes that cognitive simulation models are in vogue, as well as several attempts to simulate or model operating crew interactions. None of the techniques is deemed optimal on all criteria, and many are still not highly structured. It is noted that the Skill/Rule/Knowledge model seems to be dominant in HEI, reflected in its influence on many of the techniques.

Kirwan, B., Basra, G. & Taylor-Adams, S. E. (1997) “CORE-DATA: A computerised human error database for human reliability support.” *Proceedings of the 1997 IEEE Sixth Conference on Human Factors and Power Plants*, 9-7 to 9-12.

[Evaluation, Database]

Briefly describes a recent and ongoing effort to establish a database of human error probabilities, funded by the Generic Nuclear Safety Research Program in the UK. At time of writing it had about 400 HEPs, of which 110 were nuclear related; the others come from such non-NPP areas as offshore lifeboat evacuation, manufacturing, offshore drilling, etc.

Kleiner, C. T. & Cummings, R. L. (1994) “Risk Assessment - Including the ‘Chaos’ Factor.” *Proceedings of PSAM - II*, 80-15 to 80-20.

[Risk]

This paper discusses CHAOS as it can impact risk assessment. It is a simple concept based on a "common sense" approach to risk assessment that avoids the need to calculate probabilities and various cost/avoidance tradeoffs in favor of Risk Factor vs. Expected Time-of-Occurrence. The entire concept of risk assessment, including the CHAOS factor, is tied together with the DARTBORD computer software (DARTBORD is an eight-character designation).

In order to initialize the CHAOS factor, it is necessary to start with Steady-State in which there is no CHAOS present. The next step is to introduce possible disturbances to the system with the exact location and time yet to be determined. It is assumed that the initial "panic" precedes CHAOS. In fact, the onset of "panic" is defined as the "precursor" to CHAOS. It is also assumed that the UNIT will be biased toward stability and self-preservation and therefore, will want to prevent "panic" and avoid CHAOS. To do this, the UNIT has to (1) recognize the onset of instability and (2) know what parameters will restore control. A Risk Factor of 1 means that there is a 100% certainty that "panic" and subsequent CHAOS will occur. A Risk Factor of 0 means that there is 100% certainty that "panic" and subsequent CHAOS will not occur.

Kleinman, D. L. & Serfaty, D. (1998) “Normative-Descriptive Modeling of Human Teams: A 15-Year Perspective.” *Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting*.

[Modeling]

This paper discusses the process by which the normative-descriptive theory is applied to generate predictions of actual team performance, gives an overview of several of these models, and presents some of the findings on team decision-making performance and coordination that have emerged from this research over a 15-year period.

The key premise of the Normative-Descriptive (N-D) Modeling Approach is that motivated "expert" human decision makers strive for optimality, but are constrained from achieving it by their inherent limitations and cognitive biases. Concomitant modeling efforts have been geared to establish a mathematical framework for explaining and predicting team performance and strategy. The approach blends normative mathematical theories for team decision making with descriptive facets that capture known, and observed, human cognitive limitations and biases. The resulting normative-descriptive models have provided excellent predictions of the actual data collected in the experiments, and have shed new light on the nature of team coordination processes. Based on this theory, empirically validated normative-descriptive models have been developed that capture the complexity, dynamicity, and uncertainty of the task environment and, in turn, quantify the resulting team performance, coordination, and decision strategies in specific situations.

Kloosterman, J. (1999) “Collective significance review - A senior management level trend analysis.” Presented to the Human Performance/Root Cause/Trending Workshop.

[Modeling]

Author is at Perry NPP, First Energy Nuclear Operating Co. Collective Significance Review Committee is charged with reviewing input from various sources to determine indication of trends or action needed. One or more alert/warning flags can be identified at each meeting (approximately quarterly), with recommendations and plans.

Kohda, T., Yoshihiko, N. & Inoue, K. (1997) “Human error prediction in man-machine system using classification scheme of human erroneous actions.” *Proceedings of the 6th IEEE International Workshop on Robot and Human Communication*, 314-319.

[Modeling]

Begins with the classification system of Hollnagel, with causes (genotypes, divided into person, technology, and organization types) and effects (phenotypes, error modes). Context plays the essential role in selection of the most probable phenotype of genotype; context can be described as a set of elements of a Common Performance Condition: adequacy of organization, working condition, adequacy of man-machine interface and operational support, availability of procedures/plans, number of simultaneous goals, available time, time of day, and adequacy of training and preparation. These are differentially associated with the classes of genotypes; e.g., available time tends to affect the person, whereas adequacy of training and preparation is associated with the technology and organization. Steps for predicting human error are described; an interactive analysis support system is under development.

Koval, D. O. & Floyd, H. L., II (1998) "Human element factors affecting reliability and safety." *IEEE Transactions on Industry Applications*, 34 (2), 406-414.

[Evaluation, Human Error]

During a 10-year period, human/operator errors were tied to 7.4% of computer system interruptions for a central computer system; operator-error interruptions were apparently most frequent towards the beginning and end of a week, and highest between 8 and 9 a.m. when system loading peaked. The human element was associated with 1.7% of customer interruptions in the Canadian electrical utilities.

Kwon, K., Song, S., Park, W., Lee, J., Kim, J. (1997) "Development of the Test Simulator for Advanced Instrumentation and Control Research." IEEE Sixth Annual Human Factors Meeting.

[Methodology]

The objective of the instrumentation and control test simulator is to validate newly developed algorithms for digital control and protection and for alarm reduction, as well as to test the performance of operator support systems. EPRI's Utility Requirements Document for Man-Machine Interface Systems (MMIS) requires that dynamic models or limited-purpose simulators be used in the design of MMIS. The evaluation results of the above prototypes confirm that the test simulator performs well. The main technical issues in the current digital I&C system are common-mode failure (CMF) and software verification and validation (V&V). At present, it is almost impossible for the single test simulator to resolve the problem of CMF and software V&V without modifications.

Lanoie, P. & Trottier, L. (1998) "Costs and benefits of preventing workplace accidents: Going from a mechanical to a manual handling system." *Journal of Safety Research*, 29 (2), 65-75.

[Evaluation, Human Error]

Surveys literature on cost-benefit analysis of programs to prevent job-related accidents, all showing net profitability resulting from such programs. The current study deals with mechanization (and training and other aspects) of a wine/liquor warehouse intended to reduce noise, accident risk, and boring tasks, as well as mistakes in orders and system breakdowns. On the basis of a regression analysis to examine and control for numerous variables, it is found that the mechanization was profitable and that accidents were reduced.

Lauber, J. K. (1999) “Human Performance Issues in a Post-Deregulation Environment, Safety Cultures in a Competitive World.” *CHPCS Sixth Annual Workshop Proceedings, Human Performance: Bridging the Gap Between Research and Practice.*

[Evaluation, Safety]

The author, vice president of safety and technical affairs at Airbus, notes airline deregulation act of 1978 raised safety concerns. Says no clear indication that safety has been compromised by competition. Addresses management issues, e.g., at Valujet. Ideal safety culture is a shared belief that safety is the first priority. Notes that "safety management in a deregulated environment is a balancing act." At Delta, safety culture was measured indirectly through results (ground damage, operational incidents, accidents). Management needs to review daily reports, incident reports, etc.

Lawrence Livermore National Laboratory. (1996) *LLNL's Health & Safety Manual, Supplement 4.08 Incident Analysis Manual*.

[Modeling]

Intended to provide guidance to incident analysis committees on issues including committee operation, gathering information, and evaluation. Time-ordered event (TOE) charts are described as a means of causal event charting, and Root Cause MiniMORT charts are described as a simpler version of a Management Oversight and Risk Tree (MORT) for determining the systemic root cause(s) of an incident (the investigator is to consider a series of elements and decide which were less than adequate).

LeBot, P., Desmares, E., Bieder, C., Cara, F. & Bonnet, J. L. (1998) “MERMOS: An EDF project for updating PHRA methodology.” *Revue Generale Nucleaire International Edition*, A, 32-38.

[Modeling]

Emphasis is placed on operating during accidents; notes that "a large part of operator activity necessary for operating in an accident is not, and probably cannot be, made explicit in the procedures or the instructions as a whole. In fact, the operators exchange information between themselves and take initiatives to cope with the accident, which have a big effect on operating, outside the prescriptive area of the procedures." Authors felt it was important to go beyond a negative view of accident behavior to looking positively at the decisions and information used in these events. Uses a model of strategy, diagnosis, and action as the components of human performance during accident operation; also considers CICAs (characteristics important for accident operation), similar to error-forcing conditions. These qualitative methods have been developed, and the PHRA was set to be applied to the N4 PSA sequences beginning in 1998.

Lee, J. W., Oh, I. S., Lee, H. C., Lee, Y. H. & Sim, B. S. (1997) “Human factors researches in KAERI for nuclear power plants.” *Proceedings of the 1997 IEEE Sixth Conference on Human Factors and Power Plants*, 13-11 to 13-16.

[Human Error, Evaluation]

KAERI (Korean Atomic Energy Research Institute) organized a human factors team in 1988 and initiated 5-year human factors projects in 1992, including analysis of human error cases and development of information systems. Work on control room simulators is described, as well as an operator task simulation tool. Notes that information in trip case reports is generally too brief to analyze human errors; 79 trip events involving human error were identified from 276 trip reports. A database was developed for searching and reviewing these events, as was an authoring and representation system for use in instruction about such errors.

Lee, J. W., Park, G. O., Lee, Y. H., Suh, S. M. & Sim, B. S. (undated) “Information analysis and prototype design for the development of a database system on nuclear power plant trip event information.” Korea Atomic Energy Research Institute.

[Database]

Describes work in progress to use data from Korean nuclear power plants to develop a database system, INSTEC, for nuclear power plant trip reports. Trip case reports are reviewed and categorized. In addition, plant general information is obtained. A survey of plant personnel who saw a demonstration of the INSTEC prototype showed that people thought it would be somewhat useful for review of trip cases.

Lee, J. W., Park, G. O., Park. J. C. & Sim, B. S. (1996) “Analysis of human errors in trip cases of Korean NPPs.” *Journal of the Korean Nuclear Society*, 28 (6), 563-575

[Evaluation, Human Error]

In an analysis of barriers to reducing human errors in nuclear power plants (NPPs), authors note the complexity of NPPs (so that academic and research institutes often do not fully understand the tasks under consideration) and the "variousness" of human performance even in well-defined tasks. Urges study of actual errors from NPPs in order to determine high priorities, rather than starting with interviews, surveys, or simulator data. In this study, 255 reactor trip case reports from Korean NPPs were reviewed; 77—about 30%—were found to include human errors, with this percentage rising from below 10% in the earliest years to roughly 50% most recently.

An error classification system was developed: wrong time, wrong type, wrong object, wrong sequence, omission, quantitative lack, qualitative lack, commission, or unskilled performance; errors were also categorized by primary/secondary/other systems, work situations, and job types. The most common error type was omission (36%), similar to the 42.5% reported by Rasmussen for 200 NPP human error incidents in U.S. plants. Cross analyses were made for plant systems with job types, etc.

Legrand, F. (1996) “Improving Experience Feedback Efficiency in Human Factors in Operations at Electricite de France's Nuclear Power Plants.” IERE Workshop, Human Factors in Nuclear Power Plants

[Evaluation, Database]

Describes work of the Human Factors group at EDF since the early 1980s. Core mission is analysis of "experience feedback," incidents, events, and anomalies, including creation of a database; some 1,000 situations are covered annually. The company includes 54 reactors (pressurized water), 20 production sites, and about 20,000 people. At the start, reactor trips and safety injections were involved in more than 95% of reported incidents; now they are involved in less than one-third. Ongoing weaknesses are described, such as action without clear vision of purpose, inadequate checking, persistence of errors in operating documents, inadequate communication between operators, and excessively informal communications. Continuing efforts in human factors training and dissemination are described. Some human factors analyses involve procedural or organizational measures and behavior-related measures.

Lehto, M. R. (1991) “A Proposed Conceptual Model of Human Behavior and Its Implications for Design of Warnings.” *Perceptual and Motor Skills*, 73, 595-611.

[Modeling]

A model of human behavior is proposed that hierarchically describes levels of operator performance.

Lin, Y.-H. & Hwang, S.-L. (1992) “The application of the loglinear model to quantify human errors.” *Reliability Engineering and System Safety*, 37 (2), 157-165.

[Modeling]

Briefly reviews error models, especially quantitative approaches for computing and combining HEPs for probabilistic risk assessment. In a study, student subjects worked with an electron-beam evaporation system; their errors were counted, subjects reported what they were doing during the experiment, and a follow-up questionnaire sought additional explanations. Performance-shaping factors adapted from NUREG/CR-1278 were estimated and fit to a model that included a contingency table for the different classes of factors.

Lodal, P. N. (1997) “Advancing process safety -- What's the proper next step?” M.I.T. Conference on Organizational Processes in High Hazard Industries, http://stsfac.mit.edu/projects/risk/reports/intro.html.

[Evaluation, Safety]

Notes that the injury rate (per 200,000 hours) is lower in the chemical industry than in industry in general, but that the rates have been fairly flat over the last 10 years (although a graph shows a declining trend for chemical manufacturers). Suggests five key factors that

need to be addressed to change this performance. First, safety issues tend to be viewed separately from business issues, and therefore are not properly scrutinized nor respected. Second, changes in process safety do not have immediate consequences, so positive changes are not well reinforced. Third, business decisions are often made on a short-term basis, whereas health/safety/environmental benefits have to be assessed over a period of many years. Fourth, most business problems produce reversible changes (e.g., companies recover from marketing fiascos or from products that need to be recalled), whereas a major chemical processing accident can ruin a business. Fifth, public risk perception needs to be considered, including what is deemed acceptable.

Lopkoff, W. W. (1999) “Root Cause Report Template.” 5th Annual Human Performance/Root Cause/Trending Workshop.

[Evaluation, Modeling]

The context and quality of root cause reports varies significantly, and important areas are often overlooked. One means by which root cause reports at Three Mile Island have improved in consistency and completeness is the use of a template for the major report sections. This template guides the writing of investigators who are not adept at reporting and prompts them to complete those aspects of a comprehensive investigation that are frequently overlooked.

Love, L. & Johnson, C. (1997) *Accident Fault Trees. Human error and systems development*. Technical Report-Glasgow Accident Analysis Group.

[Evaluation, Methodology]

This paper argues that fault trees can be used to present a clear overview of major failures. The authors have extended the fault tree notation to represent traces of interaction during major failures. The resulting Accident Fault Tree (AFT) diagrams can be used in conjunction with an official accident report to better visualize the course of an accident. The Clapham Junction railway disaster is used to illustrate the argument.

This paper argues that fault trees can be used to support natural language accident reports. They provide an overview of the human factors "errors" and system "failures" that contribute to major accidents. Unfortunately, existing approaches do not capture the temporal information that can have a profound impact upon system operators. They do not capture the importance that particular failures have for the course of an accident. They only represent contributory causes and not post-accident events. The authors have, therefore, introduced an extended fault tree notation that avoids all of these limitations.

The authors have conducted a range of evaluations (Love, 1997). Initial results from these trials indicate that the extended notation can improve both the speed of access to specific materials about an accident and the overall comprehension of accident investigations. There are further methodological problems. For instance, it is difficult to recreate the many diverse contexts of use that characterize the application of accident reports. Brevity has also prevented a detailed discussion of tool support for AFT diagrams. The authors are developing

a number of browsers that use the graphical representations to index into the pages of conventional accident reports.

Maddox, M. E. & Muto, W. H. (1999) “Three Mile Island: The human side.” *Ergonomics in Design*, 7 (2), 6-12.

[Evaluation, Safety]

This provides an interview with Edward Frederick, one of the operators on duty during the TMI-2 accident on 3/28/79. At the time, operators were using event-based procedures, which require them to identify or diagnose the event before providing guidance for actions to mitigate it. That took them considerable time in this event; as a result, symptom-based procedures were introduced to allow quicker remedial actions. Notes that nuclear operators, unlike airplane or ship captains, have no direct access to information (such as looking out the window at the operating environment ahead, or hearing engine noises), having to rely completely on displays and controls; in this sense, it is an opaque operating environment.

Marcus, A. (1997) “Risk toleration: A key element in organizational safety.” M.I.T. Conference on Organizational Processes in High Hazard Industries, http://stsfac.mit.edu/projects/risk/reports/intro.html.

[Evaluation, Safety]

Suggests that organizations need to develop risk tolerance in order to prevent underlying factors from becoming proximate causes of accidents. Risk tolerance is the process of becoming aware of hazards, deciding to take actions to mitigate the hazards, and tolerating the remaining risk.

Marcus, A. A., & Nichols, M. L. (1999) “On the edge: Heeding the warnings of unusual events.” *Organization Science,* 10(4), 482-499.

[Evaluation, Safety]

Based on literature review as well as several nuclear power plant (NPP) case studies, the authors conclude that reduction in available resources leads organizations to operate closer to the edge of the safety border, with a number of potentially disadvantageous consequences. Closer to the border, NPPs are characterized by after-the-fact interventions rather than anticipation, turnover rather than retention, external search for help rather than internal development, hierarchical rather than consensual decisions, and response to imposed solutions rather than voluntary changes. NRC warnings tied to significant events cause NPPs to change their pattern of spending, especially by increasing maintenance spending.

Marsden, P. (1996) “Procedures in the nuclear industry.” In N. Stanton (Ed.), *Human Factors in Nuclear Safety*. Bristol, PA: Taylor & Francis.

[Evaluation, Performance]

Cites several studies reporting high rates of procedural deficiencies in nuclear power incidents. Procedural failures can be categorized, as by Green & Livingston: technical accuracy/completeness at fault; document poorly formatted; language/syntax problems; poorly located/cross-referenced; poor development process; insufficient verification/validation; failure to revise; and poor interrelation of training and procedures. A review of 180 human performance failures from INPO finds that "89% could be further reclassified as involving a failure of the organization to provide an acceptable degree of operator support, procedures or otherwise." Furthermore, "the majority of procedure deviations reflected unintentional deviations from procedures (67%)."

Marx, D. “An overview of the Aurora Mishap Management System (AMMS).” David Marx Consulting, Elkhorn, Wisconsin.

[Evaluation, Modeling]

Describes a Windows-based tool for airlines to perform computer-assisted mishap investigations—a tool for investigators to use while doing an investigation (asks questions, provides framework), several analysis tools (narrative search and some summary reports of the database of events), and some information sources.

Marx, D. (1998) “The Link Between Employee Mishap Culpability and Aviation Safety.” David Marx Consulting, Elkhorn, Wisconsin.

[Evaluation, Methodology]

This research surveyed more than 100 diverse aviation professionals regarding their concept of an ideal safety-centered disciplinary system. The data show that the recent call for a "blame-free" system from some safety specialists is far from what the typical aviation professional would like to see in his/her ideal disciplinary approach. Rather, the composite ideal system involves a delicate interaction between individual intent, the presence of rule violations, severity of outcome, and other attendant circumstances. Further, the analysis does make clear that airmen must not be held strictly liable for their human errors if the industry is to improve safety through its investigation of mishaps. The report suggests that the line should be drawn at recklessness—the point in the criminal and tort law where behavior moves from mere error to international risk taking.

The research is premised on the idea that a mishap disciplinary system can serve aviation safety by (1) increasing the desire of a professional airman to report a mishap that is not already known to the organization, (2) increasing the chances of open and honest participation in event investigations by those involved in a mishap, whether or not they self-report, and (3) ensuring that remedial action is taken where the need to take disciplinary action outweighs the benefits of data collected through open and honest event reporting. The

purpose of this research is to see how a diverse set of aviation professionals balances these three interests.

Four surveys were created: two to determine an ideal disciplinary approach, and two to understand current disciplinary systems used in commercial aviation. The four surveys are (1) General Survey - Ideal Disciplinary System, (2) Mishap Scenario Survey - Ideal Disciplinary Systems, (3) General Survey - Current Disciplinary Systems, and (4) Mishap Scenario Survey - Current Disciplinary System. In conclusion, based on the findings, it is clear that the industry does not support a "blame-free" disciplinary approach. The data instead support the "just" culture. Aviation safety, according to the majority of those who responded to this survey, is best served by retaining personal accountability for high-culpability errors. Unfortunately, to the erring employee, knowing whether his/her manager is one that supports discipline or not under the circumstance of an error is critical to the desire to report. (Note: the surveys mentioned are included in this paper).

Maurino, D. E., Reason, J., Johnston, N. & Lee, R. B. (1997) *Beyond Aviation Human Factors*. Brookfield: Ashgate.

[Evaluation, Performance]

The presentation is built around Reason's modeling (organizational processes linked to event by both active and latent failures) and uses the example of a 1979 air crash in the Antarctic, as well as several others. The Australian study is used to show the search for unsafe acts: errors (attentional or memory slips, and mistakes) and violations; organizational deficiencies were uncovered. Accident investigation of incidents on British railways (RAIT - Railway Accident Investigation Tool) and of controlled-flight-into-terrain incidents from the International Civil Aviation Organization shows the relative importance of certain organizational processes such as policy-making, monitoring, and managing operations.

McCafferty, D. & Borows, K.A. (1994) "Incorporation of Human Factors into Process Hazard Analysis." *Proceedings of PSAM - II*.

[Evaluation, Modeling]

In recent years, both industry and government have analyzed the factors relating to process accidents. There has been a shift away from attempts to reduce accidents through traditional safety approaches. The new focus is on Process Safety Management (PSM), which has moved away from concentrating on failures of individual pieces of equipment or injury statistics, and moved toward viewing a facility as an integrated whole, in which one part can directly or indirectly influence another. Incidents are no longer evaluated in isolation, but potential problems are evaluated for the possibility of initiating a chain of events and escalating into a catastrophic failure. Through post-incident investigations, it has become clear that the source of failures may not solely be due to equipment failures, but may be linked to the failure of administrative, human, management, or organizational factors. As a result, these factors have been recognized as playing a significant role in PSM. Since many industry practitioners are already familiar with Hazard and Operability Studies (HAZOPs), many are using this technique as their Process Hazard Analysis (PHA) methodology. Regardless of the PHA approach taken, the methodology must include evaluation of applicable human factors. There are limitations to what HFE can accomplish within the HAZOP analysis. Some of these limitations are based upon the purpose and the methodologies used, which may be thought of as HAZOP process limitations. Other constraints exist due to the limited participation in the HAZOP study of experienced and qualified HFE specialists. These limitations can be thought of as HAZOP personnel limitations.

McCallum, M.C., Raby, M., & Rothblum, A.M. (1996) *Procedures for Investigating and Reporting Human Factors and Fatigue Contributions to Marine Casualties*. U.S. Department of Transportation, U.S. Coast Guard, Report No. CG-D-09-97.

[Evaluation, Performance]

Describes a review of 279 reports of marine casualties (U. S. Coast Guard data) by Battelle researchers, with a focus on the contribution of fatigue as well as on developing and evaluating procedures for investigating casualties. Notes that a human factors taxonomy was introduced to the Marine Investigations Module of the Marine Safety Information System in 1992. For the present study, investigating officers were asked to obtain (for each incident that they judged to have a human factors causal link) information related to factors that contribute to fatigue (various sources of stress, sleep/rest cycle disruption); a 3-page form was provided to collect information about the casualty day, the work/rest schedule, and other matters. Human factors were judged by researchers to contribute directly to 53% of the incidents (as opposed to 43% by investigating officers); such direct links were highest for collisions, allisions, and groundings and were lowest for flooding, foundering, and fires. In addition to the direct role of human factors, poor maintenance practices may also have contributed.

A Fatigue Index score was derived based on number of fatigue symptoms reported, hours worked in the prior 24 hours, and hours slept in the prior 24 hours. Based on an appropriate cut-off number, 80% of cases that were judged to involve fatigue were also classified as fatigue-related by the Fatigue Index score. The fatigue contribution score of 23% overall (16% for vessel casualties, 33% for personnel injuries) was much higher than the 1.3% estimate from a 1993 study.

McCallum, M. C., Raby, M., Forsythe, A. M., Rothblum, A. M., & Smith, M. W. (2000) “Communications problems in marine casualties: Development and evaluation of investigation, reporting, & analysis procedures.” *Proceedings of the IEA 2000/HFES 2000 Congress*, 4, 384-387

[Evaluation, Human Error]

A communications model, based on previous review of marine casualty reports, was used to guide analysis of marine casualties. Communication problems (preparing/sending, transmitting, receiving, and acting on messages) are linked to contributing factors (knowledge, procedures, performance, assumptions, environment, equipment, and regulations); problems were further categorized based on the parties involved (e.g., vessel to vessel or bridge to pilot) and specific problems (e.g., transmission includes message not transmitted and message interrupted). A total of 38 out of 200 casualties were judged to have contributing communications problems; problems in preparing/sending were most frequent, especially failure to communicate. The most frequently cited contributing factor involved assuming there was no need to communicate, followed by incorrect interpretation of the situation; it is suggested that problems are tied to a strict hierarchical command culture, as well as a lack of relevant operating procedures and a lack of relevant training and practice.

McCarthy, R. L., Fowler, G., Ayres, T. J. & Gross, M. M. (1993) “An examination of the consent decree and its impact on all-terrain vehicle risk.” In F. A. Elia, Jr. & D. W. Pyatt (Eds.), *SERA-Vol. 1, Safety Engineering and Risk Analysis*. American Society of Mechanical Engineers, Book No. H00894, 155-161.

[Risk]

As a product of negotiations between the U.S. Justice Department and the U.S. Consumer Product Safety Commission (CPSC), consent decrees were filed in federal court, affecting the five largest manufacturers of All-Terrain Vehicles (ATVs). The impact of these decrees is evaluated by examining injury and exposure data collected by the CPSC. While the decrees may have had an impact on the observed reduction in usage of ATVs and a corresponding reduction in total injuries, there is no convincing evidence that action by the CPSC directly affected the behavior of ATV operators or the risk of ATV operation.

McLaughlin, T. P., Monahan, S. P., Pruvost, N. L., Frolov, V. V., Ryazanov, B. G. & Sviridov, V. I. (2000) *A review of criticality accidents – 2000 revision*. Los Alamos National Laboratory, LA-13638.

[Evaluation, Human Error]

This report reviews 22 criticality accidents in process facilities (including the recent incident at the JCO site in Toki-mura, Japan) and 38 that occurred during experiments or operations with research reactors; 19 of the 60 events were of Russian origin. Process facility accidents are of particular interest, since those facilities intend to avoid approaching critical configurations and generally are operated by people who are not technical experts in criticality physics. The report’s section on observations and lessons learned from process criticality accidents notes the following:

- No accident involved fissile material in storage or during transport.
- No accident resulted in significant radiation consequences beyond the facility (that is, these are primarily worker-safety issues);
- No accidents were solely attributed to equipment failure.
- “First and perhaps foremost, the human element was not only present but the dominant cause in all of the accidents.”
- “Second, and not often apparent, there was an element of supervisory, upper-management, and regulatory agency responsibility in all of the accidents.”
- Each accident had multiple causes.

Recommendations (lessons learned) included the following:

- "Important instructions, information, and procedural changes should always be in writing."
- "The processes should be familiar and well understood so that abnormal conditions can be recognized."
- Operations personnel need training regarding how to respond to foreseeable equipment malfunctions or their own errors, the importance of avoiding unapproved actions, approaches for dealing with criticality hazards, the importance or adhering to procedures.

The section ends, "All accidents have been dominated by design, managerial, and operational failures. The focus for accident prevention should be on these issues."

Meshkati, N. (1998) "Lessons of Chernobyl and Beyond: Creation of the Safety Culture in Nuclear Power Plants." *Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting*.

[Safety]

Claims the 58 operating Russian nuclear reactors desperately need help, including assistance regarding human and organizational factors. Described as 'bombs temporarily generating electricity," the reactors provide a substantial portion of electricity in their respective countries and therefore are unlikely to be closed soon. A Soviet-designed reactor is under construction in Cuba.

Misumi, J., Wilpert, B. & Miller, R. (1999) *Nuclear Safety: A Human Factors Perspective*. Philadelphia: Taylor & Francis.

[Evaluation, Safety]

Presents papers from a November 1996 conference growing out of collaboration between the Institute of Nuclear Safety System Inc. (Japan) and the Research Center System Safety (Germany). Sections address the four social subsystems of a nuclear power plant: individual, team, organization, and external environment. A number of authors, including Rochlin, address the characteristics of safe organizations. The most promising example of comparing incident data with predictive factors is the work of Yoshino.

Miura, H. & Arakawa, A. (1997) "Development and Validation of the Automatic Control Rods Operation System for ABWR." IEEE Sixth Annual Human Factors Meeting.

[Methodology]

Toshiba has introduced the first automatic control rods operation system for the first ABWR (Advanced BWR) in the world. The automatic control rods operation system, APR (Automatic Power Regulator), has core critical approach control, pressurization control, and power control function and covers the operation for reactor startup to about 70% electrical power. In the development of this system, a 3-D core simulator was adopted to verify the control algorithm and to validate this system. This model could verify the APR design and validate the APR system, confirming precisely the controllability of APR, and could confirm the behavior of parameters such as neutron flux, reactor period, temperature rise rate, and the distribution of thermal power. Operators could be trained with a plant simulator, in which the 3-D core model is adopted for precise simulation of flux behavior.

Moieni, P. & Orvis. D.D. (1994) "An Approach For Incorporation of Organizational Factors Into Human Reliability Analysis in PRAs." *Proceedings of PSAM - II*, 80–1 to 80-6.

[Modeling]

Discusses the inclusion of various PSFs into HRA models in order to account for organizational influences. Three general influence factors for control room personnel (tools and resources; motivation and morale; knowledge, skills, and abilities) presumably are linked to higher-level organizational factors that come under categories of decision making (centralization, goal setting, organizational learning, problem identification, and resource allocation), communications (external, interdepartmental, intradepartmental), administrative knowledge (coordination of work, formalization, organizational knowledge, and roles-responsibilities), human resource allocation (performance evaluation, personnel selection, technical knowledge, and training), and culture (organizational culture, ownership, safety culture, and time urgency). These 20 organizational dimensions were developed by collaboration among four NRC contractors (BNL, PSU, UCLA, and Accident Prevention Group).

Moody, R. E. (1995) "Failure to follow procedures (A symptom not a cause)." Presented at the ASME International Joint Power Generation Conference, Minneapolis, MN.

[Evaluation, Performance]

Says "Failure to follow procedures is a symptom of more fundamental, underlying causes, not a root cause in itself. ... In spite of efforts to upgrade content and format, procedures are often not followed ... expectations for error-free procedure usage on every task are unrealistic." Suggests in a general way that failure to follow procedures could be just personnel error in some situations, but at other times it may follow from problems of training, procedure-use/adherence-program, supervisory methods, verbal communication, self-checking program, organizational culture, work environment, the procedures themselves, or other/unknown factors. Recommends that a failure to follow procedure be dealt with first by a reaction process (identification, analysis, corrective action) and by a proactive process. Examples of reactive solutions, proactive solutions, and error prevention tips are provided.

Moore, W. H. (1993) *Management of human and organizational error in operations of marine systems*. Ph.D. Dissertation, University of California, Berkeley.

[Modeling, Database]

Dissertation describes use of a quantitative modeling methodology for human and organizational errors in marine operations. The Human Error Safety Index Method (HESIM) uses expert judgments to deal with factors that affect operator abilities to perform decisions and actions that will mitigate accident events. The U.S. Coast Guard CASMAIN system had more than 58,000 marine casualties recorded through 1992, with 71 vessel input and 37 personnel input fields, plus casualty nature and accident cause fields (including 52 human error classifications). Notes that "with CASMAIN it is difficult to determine whether human errors are the result of errors rooted in organizations or the result of individuals acting upon their own initiative." The Marine Casualty Human Factors Supplement is an addition that "relates casualty error information to the role, position, and education of the personnel involved in the marine casualty." Other marine databases include the World Offshore Accident Database and the Institute Francais du Petrole database.

The Valdez and the Piper Alpha accidents are used as extended examples for the application of HESIM; the coded accident reports in CASMAIN do not provide adequate information for such extensive analysis. Suggests that use of HESIM in advance would have shown that the level of risk was unacceptable for each of those situations. "Trends in unsafe practices, policies, procedures, and organizational contributing factors could have led to the reduction of these risks through the instigation of HOE [human and operator error] related management alternatives."

Analyses of these two incidents involves pseudo-quantitative assignment of weights to various human errors (at top-level management and mid-level and operator-level management), as well as an estimation of the impact of top-level management on mid-level (the top-level management index). Top-level factors include overall commitment to safety, commitment to long-term safety goals, cognizance of problems, competence to correct the problem, and sufficient resources to correct problems. The middle-operator level management safety index is the sum of each mid-level error's effect upon a particular human error at the operator level. The overall Human Error Safety Index is the product of 5 safety indices:

(1) The human error safety index: "quantitative measurement of human error conditional upon a set of organizational errors, human factors, system and environment factors for a specified EDA [event, decision, and action]"

(2) The organizational error index: impact of top-level management upon mid-level and operator level management error effects

(3) The human factor index: product of a stress index and a routineness index

(4) The system index: judgments as to impact of system factors on overall safety index

(5) The environmental index: product of external and internal operating condition impairment indices

Appendix 6 discusses strategies for HOE management: HOE management programs such as training, incentives, communication/information systems, safety enhancement programs, regulating/policing; changes in operating procedures; and development of HOE-tolerant or fail-safe systems. Author suggests that ongoing monitoring of a human error database can alert management to the types of errors that occur and thereby the types of corrective or preventive actions that may be most beneficial.

Moray, N. (1992) “Toward an agenda for error research.” *Proceedings of the Human Factors Society 36th Annual Meeting*, 640-643.

[Evaluation, Human Error]

Laments that there are many highly context-specific effects, so that social and cultural factors affect operator errors; notes that there are a variety of taxonomies for errors. Suggests we need to better understand the inherent structures of different tasks, in order to find commonalities. Urges research in the real world or at least in micro-worlds rather than in lab experiments in order to allow generalization. Worries that the field research needed will run into barriers of needing cross-disciplinary expertise and funding. (The paper is riddled with typos and other errors.)

Moray, N. (1999) “Monitoring, complacency, skepticism and eutactic behavior.” *Proceedings of CybErg 1999: The Second International Cyberspace Conference on Ergonomics*, 321-326.

[Evaluation, Methodology]

Suggests that for any supervisory control task there is an optimal sampling strategy, depending on the reliability and bandwidth of the displayed information. Sampling behavior can be either skeptical (sampling too often), eutactic (optimal), or complacent (too infrequent). If an abnormal event occurs during the period between samples, the operator will miss the event, even if sampling has been skeptical or eutactic; the fact that signals are sometimes missed does not establish that the supervisor is complacent—contrary to the typical claim in the vigilance literature. Consequently, it is important to use alarms and warnings, since even optimal samplers will miss signals in stochastic systems.

Morris, M. W., Moore, P. C., & Sim, D. L. H. (1999) “Choosing remedies after accidents: Counterfactual thoughts and the focus on fixing ‘human error.’” Psychonomic Bulletin & Review, 694), 579-585.

[Evaluation, Human Error]

When subjects are prompted to provide an if-only conjecture about an accident (e.g., this accident would not have happened if only the person had not hurried), human-focused conjectures are generally associated with human-focused remedies. This is suggested as a potential problem with root-cause analyses in which incident investigators tend to look for a single problem, often one attributed to human error, thereby discouraging other remedies.

Mosleh, A., Goldfeiz, E. & Shen, S. (1997) “The -factor approach for modeling the influence of organizational factors in probabilistic safety assessment.” *Proceedings of the 1997 IEEE Sixth Conference on Human Factors and Power Plants*, 9-18 to 9-24.

[Modeling]

Proposes a multiplier for the organizational influence on component failure likelihood; in the best organization, the inherent failure rate will be observed. Probability distributions are

assumed for nodes and links (the influencing factors and their connections to components). Describes the use of influence diagrams for plant sub-organizations to evaluate organizational effectiveness and yield estimates for probabilistic safety assessment.

Munipov, V. (1998) "The Problems of Nuclear Power Are Much Too Serious to Leave to Nuclear Experts." *Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting*.

[Evaluation, Human Error]

This paper discusses the lack of human factors/ergonomics forethought that went into the early designs of Soviet nuclear power plants and how this was the cause of the Chernobyl disaster.

Murray, J., Gross, M. M. & Ayres, T. J. (1999) "Human error in power plants: A search for pattern and context." *Proceedings of the Silicon Valley Ergonomics Conference & Exposition*, 187-191.

[Evaluation, Human Error]

Summary of interim findings from the literature and background review performed for the "Human Performance Management: Database & Analysis" project under EPRI's Strategic Human Performance Program. Ties "organizational epidemiology" work to other strategic research focused on automated text analysis of (text-based) reports from energy facilities (see EPRI report 1004664).

Muschara, T. (1997) "Eliminating plant events by reducing the number of shots on goal." *Proceedings of the 1997 IEEE Sixth Conference on Human Factors and Power Plants*, 12-1 to 12-6.

[Evaluation, Performance]

NPPs had 2.4 significant events per year in 1985, declining to less than .07 each in 1996**;** human performance rose from being attributed in about 50% to about 70% of those incidents. Human performance can be related to conditions at the individual, leader, and organizational behavior levels. An error event has 4 elements: initiating actions, error precursors, flawed defenses, and latent organizational weaknesses (which are said to account for about 80% of the causes of plant events; no citation given).

Nagel, D.C. (1998) "Human Error in Aviation Operations." In *Human Factors in Aviation*.

[Evaluation, Human Error]

This chapter provides a description of methods of studying error and models of errors, plus discussion of decision-making and action errors. No completely adequate understanding of human error exists, but significant progress is being made to achieve that understanding. Even the author's simple framework for discussing error in a systematic fashion should help

the reader to better understand the basis for error in the operation of a complex system, such as the national airspace system, and to understand that the solutions to the error problem must be developed in just such a "system context." Working on any one component of the system is bound to fail at some level. All components are interdependent, and changes in any one eventually are reflected in the others. For just this reason, attempts to increase levels of aviation safety solely through the use of automation, as is sometimes suggested, cannot succeed. Finally, automation, which can have a very positive effect on both efficiency and safety, can also have a depressing effect on safety. As pilots are removed from an active role in flying the aircraft, more and more incidents that can only be termed "loss of situational awareness" are reported. The reports are particularly prominent when the automatic systems either fail to perform as the pilots expect them to or, sometimes, fail to perform at all.

Nakajo, T. (1993) “A method of identifying latent human errors in work systems.” *Quality and Reliability Engineering International*, 9 (2), 111-119.

[Evaluation, Methodology]

Notes one type of countermeasure is foolproofing, i.e., improving work systems to prevent human errors. Notes that a problem with using FMEA for human errors is the difficulty of specifying all possible human errors. In order to deal with this, a data set of 1002 errors was collected from various manufacturing processes; clustering with the affinity diagram method yielded 16 error modes. These are taken to be the universe of human error modes, encompassing memory, perception, and response activities. A work system is decomposed into segments, and then the 16 possible error modes are considered for each segment. "Using the 16 error modes presented together with the previous work system decomposition criterion makes it possible to list all latent human errors systematically without having any special human engineering knowledge, thereby significantly decreasing the probability of an omission."

Next, priorities for countermeasures can be assigned by ranking each human error in terms of the possibility, criticality, and localizing effects (degree to which the effects of the error have already been localized or restricted). Finally, foolproofing methods can be developed for the most important errors; foolproofing is accomplished by elimination (changing key work system characteristics), replacement (automation of key operations), facilitation (making certain operations easier), detection (detecting human error consequences and taking corrective action), or mitigation (adding operations to reduce error effects). Several test applications to manufacturing are described.

Nakatani, Y., Nakagawa, T., Terashita, N. & Umeda, Y. (1997) “Human Interface Evaluation by Simulation.” IEEE Sixth Annual Human Factors Meeting.

[Control Room, Modeling]

Proposes a new method to evaluate human interface design of plant equipments from the viewpoint of human error. The system, called DIAS, is implemented on the workstation, and it consists of the maintenance personnel model and the equipment interface model. The maintenance personnel model stores the standard maintenance procedures, which are represented by the augmented Petri net model. DIAS analyzes the potential human errors of each task in the simulation results by using the human-error-mechanism knowledge base combined with a quantitative human error rate prediction technique. The equipment interface model can be easily redesigned on the graphical editor, which enables the analyst to evaluate alternative designs. As a dynamic evaluation method, the SEAMAID system evaluates the control panel of the nuclear power plant from the viewpoint of human error, by integrating the human operator simulation model, the human system interface model, and the plant simulator. As a static method, THERP (Technique for Human Error Rate Prediction) is used in the nuclear power plant design.

National Research Council (1994) *Organizational Linkages, Understanding the Productivity Paradox*. Washington: National Academy Press.

[Evaluation]

Numerous studies (though not all) have found evidence for the “Information Technology (IT) Productivity Paradox”—that heavy investments in information technology have not been met with correspondingly enhanced productivity, either in comparisons between firms or in larger inter-industry or economic sector analyses. Numerous possible explanations are considered, including difficulties in switching to the new technologies, changes in the nature of interpersonal communication, improved quality (but lower quantity) of work, lack of skill or training, increased workload or administrative overhead, competition, and increased expectations for customer service. The papers explore methodological issues and proposed explanatory mechanisms. The concluding chapter points to organizational linkages: productivity improvements at one level or location in an organization can have undesirable effects elsewhere; also, organizational factors can prevent productivity improvements at the level of individual workers from being realized at higher levels. Thus, IT investments (or any attempts to improve productivity) need to be considered within a full organizational context in order to anticipate net effects.

Nelms, C.R. (1997) “The Latent Causes of Industrial Failures. How to Identify them, and What to Do About Them.” IEEE Sixth Annual Human Factors Meeting.

[Evaluation, Methodology]

Private consultant says that identifying latent causes of a failure should begin with a "WHY Tree" to summarize physical causes of the failure and the points of inappropriate human intervention. The root cause of all failures is "the human condition," but there can be many latent causes of a failure, including the decisions people make that they know are wrong (e.g., doing something quickly when you know you should take more time, cutting staffing when you know that will increase workload, etc.). The main agent for change following a failure is direct involvement in root cause team sessions, which involve discussions of why people acted as they did, so that latent causes can be identified and addressed.

Nelson, W. R. (1997) “Integrated design environment for human performance and human reliability analysis.” *Proceedings of the 1997 IEEE Sixth Conference on Human Factors and Power Plants,* 8-7 to 8-11.

[Evaluation]

The integrated design environment used at Idaho National Engineering and Environmental Laboratory includes lessons learned (qualitative information from operational experience, based on analytical methods that can be applied to interpret operational data), functional analysis, simulation, human performance/human error analysis, and design engineering tools (including THEA, the Tool for Human Error Analysis, developed for NASA for aircraft design).

Norros, L. & Hukki, K. (1994) “Development of an Orientation Based Approach to Evaluation of Process Operators' Expertise.” *Proceedings of PSAM - II,* 26-9 to 26-14.

[Evaluation]

Research attempts to define the generic, common problems of expertise that must underlie specific demands in routine and crises situations. It has been assumed that through tackling these common problems, it would be possible to find a coherent approach to expertise in this work. The concept of orientation, which was utilized originally by Galperin (1979) and refers to a person's way to frame a problem situation, is central in the investigators’ approach. It is used to define the operators' way to cope with the problems of interpretation of information. This concept is used as a means to relate routine work and critical decision-making in rare situations with each other and to conceive the roles of these seemingly polarized demands in the formation of expertise.

Oliver, R.M. & Yang, H.J. (1990) “Bayesian Updating of Event Tree Parameters to Predict High Risk Incidents.”

[Modeling, Evaluation]

In this chapter, the authors use chance influence diagrams to describe event trees employed in safety analyses of low-probability, high-risk incidents. This chapter shows how much the branch parameters (chance of subsystem failure) used in the event tree models can be updated by a Bayesian method based on the observed counts of certain well-defined subsets of accident sequences. The chapter concludes with a numerical example, which shows how information contained in low-severity incidents can be used to improve the prediction of the most severe incidents that typically are so rare that they have not yet occurred. The example shows how data obtained in relatively short time periods can play an important role in sharpening predictions for severe incidents where data may not become available for very long periods.

Orendi, R.G. (1997) “Human Factors Experience in Designing a Modern Control Room for a VVER-1000 Nuclear Plant.” IEEE Sixth Annual Human Factors Meeting.

[Control Room]

The Temelin Nuclear Power Plant is located in the south Bohemia region of the Czech Republic and consists of two VVER 1000-MW units. The new automated electronic systems currently being implemented at Temelin have resulted in an upgraded, state-of-the-art I&C system that meets both domestic and international safety and design standards. This paper describes these various automated systems and how the operator utilizes these systems in both the main and emergency control rooms.

The Temelin plant includes soft controls for non-safety systems. The safety systems use dedicated digital controls on a conventional standup panel in both control rooms. Since digital technology is used throughout, diverse systems have been designed to protect against common-mode failures. This paper discusses the man-machine interfaces and control/display integration issues associated with this unique combination of soft and fixed-wire controls.

Orvis, D.D., Moieni, P. & Spurgin, A.J. (1994) “Causal Factors of Operator Unreliability: An Application of Simulator Data.” *Proceedings of PSAM - II*.

[Evaluation, Safety]

Regulators, energy companies, and INPO have begun to compile statistics on types and causes of "inappropriate actions" by control room and plant personnel; however, the data is collected *post facto*. By routinely collecting data during simulator training and re-qualification exercises and analyzing the data for types and causes of "deviations" or "inappropriate actions," the operating plant can take corrective actions before such "deviations" occur in the plant or lurk as "resident pathogens" that increase the probability of operator error and thereby increase the probability of a catastrophe. This paper demonstrates how simulator data can be used to quantify the relative importance of various immediate or proximal causal factors and discusses how such data may be applied to identify and quantify the influences of deficient organizational factors. (See the *PSAM-II* paper by Bareith *et al*. [1994] for a similar treatment of simulator data.) Reviews of several simulator studies are provided.

Ostrom, L.T. (1994) “The Pros and Cons of Using Human Reliability Analysis Techniques to Analyze Misadministration Events.” *Proceedings of PSAM - II*.

[Modeling]

This paper discusses the risk assessment methodologies applied to data collected during investigations of incidents in medicine involving nuclear by-product materials. These are called misadministration events. This work represents one of the first applications to the safety of medical radioisotope devices of probabilistic risk assessment (PRA) techniques developed to evaluate reactor safety.

This paper discusses the methodology used to date, the problems encountered, preliminary insights from this first analysis, and possible future directions of the project. The risk assessment highlighted (a) the failure path that lead to the event, (b) the estimated effects of licensee's corrective actions on the failure path, and (c) another failure path that is not only reasonably probable but could go undetected. The analysis process also showed the sequence of events and how the performance-shaping factors at the facility affected the outcome. Also, it gives a reasonable estimate of risk reduction after postulating changes to the facilities process.

The risk assessment methodology did not provide all the benefits desired. It did not provide a good quantitative estimate of the risk of future misadministrations. Lack of a specific human reliability database that addresses human errors for medical procedures and specific hardware failure rates for medical equipment lead to the methodology producing less than ideal results.

Pandey, D. Jacob, M. & Tyagi, S. K. (1996) "Stochastic modeling of a powerloom plant with common cause failure, human error and overloading effect." *International Journal of System Science*, 27 (3), 309-313.

[Modeling]

Complex mathematical treatment of a simple system, using a state transition diagram and various error probability distributions.

Panko, R.R. (1997) "Theories of Human Error."

[Evaluation, Human Error]

This paper reviews several theories of human error and provides a table with 44 basic error rates and a bibliography with 101 references.

Park, K. S. (1997) "Human error." In G. Salvendy (Ed.), *Handbook of Human Factors and Ergonomics*. John Wiley: New York.

[Evaluation, Modeling]

Cites reports of 20-80% of system failures resulting from human error. Notes that human errors can be due to task complexity, error-likely situations, or behavioral characteristics. Rook (1962) classified errors in terms of the behavior component (input, mediation, or output) and the intent (intentional, unintentional, omission). Rasmussens's step-ladder model (1976) allowed for errors to be produced by otherwise efficient cognitive shortcuts. Rasmussen (1982) saw performance-shaping and situation factors as mediating the likelihood that environmental events would lead to (skill-, rule-, or knowledge-based) errors. Reason (1987) developed the Generic Error Modeling System (GEMS) starting with Rasmussen's step ladder to model cognitive errors; skill, rule, and knowledge levels are differentiated on the basis of the types of errors that occur and the error-shaping factors that apply. Rouse & Rouse (1983) classify errors on the basis of behavioral processes (observation of system state, choice of hypothesis, testing of hypothesis, choice of goal, choice of procedure, execution of procedure) and the task-related erroneous decisions or actions at each stage. The human error probability (HEP) approach is discussed in some detail. The four basic sources of data for human error databases are field, simulator activities, laboratory experiments, and expert judgment. THERP (Technique for Human Error Rate Prediction) is associated with Swain & Guttman (1983); it uses event trees with binary decision branches and conditional probabilities.

Park, K. S. & Jung, K. T. (1996) "Considering performance shaping factors in situation-specific human error probabilities." *International Journal of Industrial Ergonomics*, 18 (4), 325-331.

[Modeling]

Notes that the HEPs provided in the Swain & Guttman handbook are nominal, based on average industrial conditions, and need to be modified by performance-shaping factors (PSFs). One approach is SLIM, the success likelihood index methodology of Embrey *et al*. (1984), in which the log success probability of a task is related to the success likelihood index, which depends on the combined effects of PSFs. This paper describes a quantitative approach in which HEPs are distributed lognormally. Notes problems: choosing the most important and relevant PSFs for a task and assuming independent contributions by the PSFs.

Park, K. S. & Jung, K. T. (1996) "Estimating human error probabilities from paired ratios." *Microelectronics and Reliability*, 36 (3), 399-401.

[Modeling, Evaluation]

Describes a procedure for estimating HEPs by having people judge the likelihood ratios for pairs of errors; e.g., for a set of 7 possible errors, subjects produced ratio estimates for all pairwise combinations. Notes that this process would become tedious with large sets of errors, and suggests they could be divided into manageable subsets.

Parry, G.W. (1994) "The Need for, and a Proposed Structure of, A Second Generation HRA Methodology." *Proceedings of PSAM - II*.

[Modeling]

Argues that HRAs have generally lacked an understanding of the mechanisms of human error, especially for errors of commission. Suggests that both trigger events and conditioning events need to be considered, and that operator understanding of plant state is an important factor in the success of error recovery.

Parry, G.W., Julius, J.A., Jorgenson, E., & Mosleh, A.M. (1994) "A Procedure for the Analysis of Errors of Commission in a PSA." *Proceedings of PSAM - II*.

[Evaluation, Human Error]

Describes an application of study of human error, such as Parry advocates elsewhere. Following an event in a nuclear control room, errors can be of three types: global misdiagnosis, local misdiagnosis, or slip; this paper discusses global misdiagnosis errors.

Pate-Cornell, E. (1989) "Organizational extension of PRA models and NASA application." *Proceedings of PSA '89*, American Nuclear Society.

[Modeling, Evaluation]

PRA modeling is extended through a Bayesian analysis of task sequences, including technical and organizational failures that can affect system reliability. The process is analyzed to identify normal performance and potential problems; next, organizational procedures and incentives are analyzed to determine probability that an error will be observed, recognized, communicated and corrected before it causes a system failure. Using computed probabilities, a probabilistic risk analysis is performed, and the results are integrated with an event tree or influence diagram. This paper is an overview of application of this approach to the thermal protection system of the space shuttle; a more complete treatment of the method is cited as Pate-Cornell & Bea (1989).

Pate-Cornell, E. (1997) "Ranking and priorities in risk management: Human and organizational factors in system failure risk analysis and a maritime illustration." M.I.T. Conference on Organizational Processes in High Hazard Industries.

[Modeling]

PRA explicitly includes system errors attributable to human errors, but may not include errors that affect the probabilities of the basic events; sometimes it is said that 80-90% of failure risk is tied to human error, but applying this globally can cause problems. Since virtually all failures could be attributed to human error, this does not help in ranking safety measure priorities; furthermore, the contribution of human error can vary across systems and across accident types. There are different types of error, e.g., gross errors (unquestionable mistakes) vs. errors of judgment, that reflect response to uncertainties, and people at different levels in an organization may have different attitudes towards risk. Murphy & Pate-Cornell describe the SAM model (Systems, Actions, Management). The contribution of different types of human error to each element in the PRA is assessed. A distinction is made between human errors that are directly part of the PRA and those human decisions and actions that influence the probabilities of technical failures and other errors, as well as the effect of management factors. Thus, as shown in influence diagrams, management factors influence decisions and actions that influence events in the PRA. This approach has been applied to space shuttle tiles, offshore platforms, and patient risks in anesthesia.

Pate-Cornell, N. E. & Bea, R. G. (1989) *Organizational aspects of reliability management: Design, construction, and operation of offshore platforms*. Research Report No. 89-1, Department of Industrial Engineering and Engineering Management, Stanford University.

[Modeling, Evaluation, Human Error]

Describes PRA work for offshore platforms. Chapter 2 offers a taxonomy of organizational errors into 16 subcategories based on whether they are gross errors involving communication, cognitive problems, or human limitations or errors of judgment of various types. The rest of the paper discusses several case history incidents, and it goes through the details of PRAs including the use of influence diagrams.

The analyses lead to several observations: It is necessary to categorize the types of human errors involved when doing PRAs. Accumulated errors affect failure probability. Errors of judgment make a major contribution to failure probability. Time pressure on the critical path can increase failure likelihood. And incentives can affect judgment in balancing safety and productivity.

Pedrali, M. & Cojazzi, G. (1994) "A methodological framework for root cause analysis of human errors." *Proceedings of the 21st Conference of the European Association for Aviation Psychology*, 143-148.

[Modeling]

Authors are from France (Centre National de la Recherche Scientifique, ARAMIIHS) and Italy (Commission of the European Community, Joint Research Centre, Institute for System Engineering and Informatics). Proposed root cause analysis (RCA) is divided into erroneous action identification (EAI) and causal analysis (CA). EAI consists of data collection, event time lines, and action detection; actions that deviate from proper procedure and which cannot be justified (unavoidable due to circumstances such as a faulty instrument) are considered as erroneous actions. For CA, the taxonomy proposed by Hollnagel (Hollnagel & Cacciabue, 1991) and modified by Cacciabue (Cacciabue *et al*., 1993) is used; causes are divided into system-related (external) and person-related (internal) causes. The Simplified Model of Cognition consists of observation, interpretation, planning, and execution. The general or specific effects of behavior, called phenotypes, are linked to general and specific causes using tables (details not provided).

Perin, C. (1997) "Issues in organizing and managing high-hazard production systems." M.I.T. Conference on Organizational Processes in High Hazard Industries, http://stsfac.mit.edu/projects/risk/reports/intro.html.

[Evaluation, Database]

Notes that many who are responsible for high-hazard organizations lack knowledge of how to manage human error and how to balance technical and organizational issues. Urges such organizations to see near misses as experiments or chances to learn about the state of the system and to bring outsiders as friendly critics to avoid problems of groupthink.

Perin, C. (1999) “Toward More Robust Analyses of Events and More Effective Corrective Actions.” *CHPCS Sixth Annual Workshop Proceedings, Human Performance: Bridging the Gap Between Research and Practice*.

[Evaluation, Performance]

Suggests that "event investigations and corrective actions often neglect social and cultural system conditions (soft) in favor of hard. More effective corrective actions depend on more robust event and operational analyses that combine hard and soft." Describes review of several incidents where social/organizational problems played important role.

Phillips, L.D. & Humphreys, P. (1990) “A Socio-technical Approach to Assessing Human Reliability, Influence Diagrams, Belief Nets and Decision Analysis.” 253-276.

[Modeling]

Describes "socio-technical assessment of human reliability" (STAHR), drawing upon decision theory for error rates and group process work (experts interacting). Uses simple influence diagrams (a target event, which is correct performance by a human operator, and the related events that can influence the target event), with the links provided by expert judgments. The process of developing a model is described in detail.

Phimister, J. R., Oktem, U., Kleindorfer, P. R. & Kunreuther, H. (2000). *Near-miss system analysis: Phase I*. Wharton School, Center for Risk Management and Decision Processes.

[Human Error]

In this report, impacts of key issues on near-miss programs are outlined, and benchmark characteristics of successful near-miss programs are identified.

Pirus, D. & Chambon, Y. (1997) “The computerized procedures for the French N4 Series.” IEEE Sixth Annual Human Factors Meeting.

[Evaluation]

After a brief discussion of the main characteristics an efficient operating system should have, a presentation is given of operating system processing, allowing benefits in terms of quality of the operation, reduction in alarm occurrence, and operator presentation. The article goes on to discuss in detail each of the components of the computerized control room.

Pyy, P. & Andersson, K. (1997) “Integrated sequence analysis - A solution to HRA problems?” *Proceedings of the 1997 IEEE Sixth Conference on Human Factors and Power Plants*, 9-1 to 9-6.

[Evaluation]

Describes a research program in the Nordic countries, especially integrated sequence analysis (ISA): "event analysis with active participation from different disciplines such as PSA/probabilistic analysis, thermohydraulics, psychology, etc."

Pyy, P., Laakso, K. & Reiman, L. (1997) “A study on human error related to NPP maintenance activities.” *Proceedings of the 1997 IEEE Sixth Conference on Human Factors and Power Plants*, 12-23 to 12-28.

[Evaluation, Human Error]

Because of the importance of common-cause failures (CCFs) for increasing risk (by affecting several trains of a safety-related system), there is interest in human-induced CCFs (HCCFs), in which repeated wrong actions are involved, and in human-shared equipment failures (HSEFs), in which a single human error interacts with components and systems to yield multiple consequences.

This study used 4407 fault and repair history records and other utility reports from a Nordic nuclear power plant. Review by analysts and foremen yielded 334 human error cases, of which 14 cases were classified as HCCFs or HCCNs (human-induced non-critical faults). Of these, 206 were considered single-error cases. Errors were categorized according to the equipment involved and Swain's taxonomy (omission, commission, wrong direction, other, wrong set point). Commission errors were especially high in instrumentation and control and mechanical equipment, whereas omissions were common in actions on instrument line block valves. Errors were compared during different phases of plant operation; errors are especially likely during outages (because of the amount of maintenance that takes place), but most of these are not discovered until plant operation resumes.

Quinn, C. & Walter, K. E. (1997) “Identification of error patterns in terminal-area ATC communications.” *Proceedings of the Human Factors and Ergonomics Society 41st Annual Meeting*, 1381.

[Evaluation, Human Error, Databases]

This poster describes a review of 122 ATC violation incidents from the ASRS (Aviation Safety Reporting System), a voluntary reporting system with confidentiality provisions. Narratives were coded, analyses were conducted, and common patterns were identified. In half of the incidents, the error was noticed in time to take action, but in nearly 40% of such cases there were additional errors during the recovery attempt. "This analysis demonstrates that redundancies in the present ATC system may not be sufficient to support large increases in traffic density."

Ramey-Smith, A.M., Thompson, C.M., Persensky, J.J. (1997) “Human Reliability Assessment and Human Performance Evaluation: Research and Analysis Activities at the U.S. NRC.” IEEE Sixth Annual Human Factors Meeting.

[Modeling, Evaluation]

Describes NRC programs built around 5 general strategies:

– Operating event analysis and database maintenance to support HP evaluation and HRA,
– Technical basis for HP evaluation and HRA,
– Technical basis and guidance on management and organizational influences,
– Integrated model of HP and human reliability, and
– Dialogue and cooperation and HP evaluation and HRA methods and data.

Rankin, W.L., Allen, J.P. & Sergeant, R.A. “Maintenance Error Decision Aid: Progress Report.” http://www.hfskyway.com/hfami/mtng11/t11_pr4.htm

[Evaluation, Human Error]

Boeing, working with three of its customer airlines—British Airways, Continental Airlines, and United Airlines—developed a process for following up maintenance-error-caused events in order to determine what contributed to the error so that corrective actions can be taken to eliminate or reduce the probability of future similar errors. The process is called the Maintenance Error Decision Aid (MEDA). The philosophy of the process is as follows: (1) maintenance technicians do not make errors on purpose; (2) maintenance errors result from a series of contributing factors; (3) many of these contributing factors are part of airline processes and can be managed; and (4) some individual errors will not have specific corrective actions. Beginning in November 1995, Boeing began to work with its customer airlines to help them implement MEDA. Since November 1995, the authors have trained over 40 airplane maintenance organizations on the MEDA philosophy, process, and investigation techniques.

Reason, J. “Approaches to Controlling Maintenance Error.” http://www.hfskyway.com/hfami/mtng11/t11_pr3.htm

[Evaluation, Human Error]

Rapid technology advances in aviation have not only meant the replacement of human control by computers, they have also brought about very substantial improvements in the reliability of equipment and components. But the maintenance schedule for a modern aircraft still demands the repeated disassembly, inspection, and replacement of millions of removable parts over its long working life.

As recently as 20 years ago, these inspections would have resulted in the frequent detection and replacement of failed components. Then, the risks of in-flight failure due to intrinsic engineering defects probably outweighed the dangers associated with allowing legions of fallible people access to the vulnerable entrails of the aircraft. But now the balance has tipped the other way. The greatest hazard facing a modern aircraft comes from people, and most particularly from the well-intentioned but often unnecessary physical contact demanded by the current maintenance schedules.

Listed below are the top seven causes of 276 in-flight engine shutdowns: incomplete installation (33%), damaged on installation (14.5%), improper installation (11%), equipment not installed or missing (11%), foreign object damage (6.5%), improper fault isolation, inspection, and test (6%), and equipment not activated or deactivated (4%). This paper focuses on two recently developed error management techniques: ERK (the Error Reduction Kit) aimed at error-prone tasks; and MESH (Managing Engineering Safety Health) designed to identify proactively those factors within both the workplace and the organization that are likely to promote errors and impede their recovery.

Reason, J. (1990a) *Human Error*. New York: Cambridge University Press.

[Modeling]

Surveys models and definitions, including Reason's GEMS (generic error-modeling system), which relies on skill/rule/knowledge classification from Rasmussen (skill-based slips and lapses; rule-based mistakes; knowledge-based mistakes). Relies primarily on psychological studies and theorizing. Many concepts are discussed elsewhere, including errors vs. violations, defense in depth, and latent vs. active errors.

Reason, J. (1990b) “Managing the Management Risk: New Approaches to Organisational Safety.” *Workshop on Managing New Technologies*, 1-16.

[Evaluation, Safety]

Safety concerns have gone through three phases: the technical age, when the main focus was on operational and engineering methods; the human error age, addressing human error in incidents such as Three Mile Island; and now the socio-technical age, mainly resulting from incidents in complex, well-defended technologies (Bhopal, Chernobyl, Piper Alpha) and dealing with interactions between technical and social aspects of a system. Reason discusses his resident-pathogen metaphor: complex systems need more pathogens to produce an accident, higher management has greater potential for spawning pathogens, local triggers are hard to anticipate, systems with more pathogens are more prone to accidents, and proactive identification of pathogens (latent failures) holds promise (establishment of diagnostic organizational signs, analogous to white blood cell counts or blood pressure).

Suggests that every production system consists of decision-makers, line management, preconditions, productive activities, and defenses. Human contribution to organizational accidents can happen at each level: fallible decisions, line management deficiencies, psychological precursors of unsafe acts, unsafe acts, and inadequate defenses. Discusses work on errors in oil production, identifying 11 general failure types: hardware defects, design failures, poor maintenance procedures, poor operating procedures, error-enforcing conditions, poor housekeeping, system goals incompatible with safety, organizational failures, communication failures, inadequate training, and inadequate defenses. These, in turn, may emanate from three source types that others characterize as organizational culture: commitment to safety, competence to achieve safety goals, and safety awareness.

It is not possible to learn about these underlying failure types from examining the failure tokens that are observable, because the mapping is not simple one-to-one. Need a combination of performance indicators (such as those used by INPO and NRC for efficiency, plant safety, and worker safety), and organizational indicators (which could relate to issues such as quality of plant's safety information system, status of safety-related staff, awareness of hazards, etc.).

Reason, J. (1991) "The dimensions of safety." In J. Patrick (Ed.), *Cognitive Science Approaches to Cognitive Control*, Third European Conference, Cardiff: University of Wales.

[Safety]

Chapter in book.

Reason, J. (1997) *Managing Organizational Risks*. Ashcroft: Brookfield.

[Evaluation, Safety]

The latest complete survey of Reason's progress, including his models of errors and organizations, his notion of safety space, the value of analyzing incident reports, and the development of proactive tools such as Tipod-Delta and MESH for monitoring workplace safety factors. A safety culture needs to have the characteristics of being a reporting, just, flexible, and learning culture.

Reason, J. (1998) *Recurrent Accident Patterns*.

[Evaluation, Human Error]

Based on review of accident data (examples are given from aviation, nuclear power generation, and marine transport), it is suggested that recurrent accident scenarios involve the following:

- Universals - ever-present hazards such as rocks for ships or bad weather for planes;
- Local traps - "characteristics of the task or workplace that, in combination with human error and violation tendencies, lure people into repeated patterns of unsafe acts of less-than-adequate performance"; and
- Drivers - motivation, such as from an unsafe culture in an organization; organizations have to balance safety and production, with competitive pressure pushing towards productivity.

Reason, J. (2000a) “Organizational accidents, human performance, and safety.” Presentation to the Workshop on Leading Indicators of Human Performance, Rochester, NY.

[Performance]

Discussion of organizational factors in industrial accidents, such as at the nuclear fuel reprocessing facility in Japan.

Reason J. (2000b) “Safety paradoxes and safety culture.” *Injury Control and Safety Promotion*, 7(1), 3-14.

[Safety]

Discussion of the conflict between productivity and safety, and of the difficulty of defining what is “safe enough” unless some variability is permitted.

Reichelt, R.A., Eichorst, A.J., Clay, M.E., Henins, R.J., DeHaven, J.D., Brake, R.J. (1999) *Occurrences at Los Alamos National Laboratory: What Can they Tell Us?* Los Alamos National Laboratory, LA-UR-99-1569.

[Evaluation, Safety]

Each year Los Alamos National Lab has 250 incidents meeting DOE reporting criteria; the Occurrence Investigation Group assists in investigations. There has been progress towards responding to low-consequence incidents. Investigations revealed problems in management systems and safety culture (e.g., management belief that R&D was difficult to predict and therefore not subject to procedural constraints; perception by workers that they must produce; lack of management involvement in daily activities; targeting of worker errors in past occurrences; etc.).

Reiman, L. & Norros, L. (1994) “Organizational Assessment of a Maintenance Department at a Nuclear Power Plant.”

[Evaluation, Performance]

"Our attempt... was to understand the mechanisms of work culture and to find means to promote such development." Interviews were conducted with people from the management, foreman, and technician level of the maintenance organization at a nuclear power plant, regarding work problems and how they dealt with them to achieve high quality. It was found that there was common awareness of internal conflicts, but leadership was less than optimal in terms of setting goals and monitoring/assessment. Technicians placed high reliance on following rules rather than contributing to development of expertise.

Reynes, L.J. (1994) “Level of Knowledge and Safety.” *Proceedings of PSAM - II*, 29-5 to 29-11.

[Evaluation, Safety]

Suggests that nuclear plant operators need not only practical training in plant operation but also general knowledge in order to organize their skills, as well as for understanding and managing unusual situations. Review of incidents at EDF plants is of limited value for studying the value of general knowledge because such analysis has usually involved looking for deviations from procedure; it was noted, however, that some operators had difficulty when it was necessary to keep track of several parameters, for which theoretical knowledge is needed, or when understanding of reactor behavior was important. A new database, initiated in 1993, is expected to improve causal analysis, especially of human factors.

Ringstad, A. J. & Szameitat, S. (2000) “A comparative study of accident and near miss reporting systems in the German nuclear industry and the Norwegian offshore industry.” *Proceedings of the IEA 2000/HFES 2000 Congress*, 4-380-383

[Database]

Accident and near-miss reporting systems (ASMASs) ideally should include complete and valid input data, identification of relevant causes and statistical patterns, and cost-efficient corrective actions. It was found that the Norwegian offshore industry typically reports ~900 incidents per year per installation, compared to only 10-40 per German NPP; this reflects different definitions of reportable incident, although the actual number of formal investigations was nearly the same. For the offshore industry, there is a central database operated independently; for NPPs, significant incidents are reported to a central database.

Roberts, K.H. & Grabowski, M. (1994) “Some Requirements for Designing and Managing Reliable Complex Systems.” *Proceedings of PSAM - II*, 40-1 to 40-8.

[Evaluation, Performance]

Discusses complex systems such as networked organizations. Notes that in the case of the Exxon accident, various organizations were interdependent, but members did not understand the interdependence. Presumably most complex organizational systems just grow, but managers will be faced increasingly with the design of such systems. Issues of prime importance are suggested:

– Someone needs to be in charge of having the big picture;
– Appropriate tension between tight and loose coupling (since either can have problems);
– Balance between aggregated and disaggregated decisions;
– Organizational system communication - encouraging lots of communication helps the system;
– Nurturing the system culture so members understand its norms; and
– Improved human-computer interfaces, with strong consideration of interface design.

Robertson, M.M. (1998) "Human Factors Training as a Change Agent in Complex Work Environment." Fifth Annual Workshop Expanding Human Performance Envelopes: Tools for Industry.

[Evaluation, Safety]

Summarizes human factors training case study in aviation maintenance: Maintenance resource management is said to "improve safety by increasing coordination and exchange of information between team members and between teams of airline maintenance crews." Evaluation by questionnaires, interview/observations, and performance measures. Claimed beneficial; few details provided in this set of slides.

Robertson, M.M., O'Neill, M., Robinson, M., Sless, J. (1998) "Measuring the Impact of Work Environment Change Programs: A System Approach." *Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting*.

[Methodology]

Describes application of a systems analysis model to office work: define the problem, set objectives and evaluation criteria, develop alternatives, model alternatives, evaluate alternatives, select an alternative, and plan for implementation/evaluation/modification.

Robisson, F. (1998) "Allowance for the human factor in the design, preparation and execution of maintenance operations." *Revue Generale Nucleaire International Edition*, A, 11-14.

[Evaluation, Human Error]

Describes work by Framatome, a designer/vendor of nuclear plants. Starts with assumptions attributed to INPO: man is fallible, man seeks to improve, and human error can be managed though not eliminated. Talks of importance of an organizational entity or framework for monitoring "ordinary" errors, utilizing feedback from operational experience to improve operations.

Rochlin, G.I. & von Meier, A. (1994) "Nuclear Power Operations: a Cross-Cultural Perspective." *Annual Review of Energy and the Environment*, Vol. 19, 153-187.

[Evaluation, Performance]

Study focused on PWR control rooms in Europe and the U.S. In the U.S., regulation and scrutiny affect operator behavior to an extent not found in other settings such as ATC, aircraft carrier flight operations, and utility grid management; NPP risk is so high that organizations are unlikely to modify established behavior patterns.

Review of literature and their own NPP observations lead the authors to downplay the "convergence" hypothesis (which holds that national or other cultural differences become unimportant as technological industries evolve towards optimal structure); to the contrary,

culture is said "to be responsible for functionally significant differences between similar plants" in Germany, France, and Great Britain.

Based on interviews with plant staff of various departments and levels at a series of NPPs, the authors found some similarities, including concern with openness and responsibility as important for safety, as well as an emphasis on safety (a safety culture); a diversity of subcultures within each site (e.g., engineers vs. operators); and rejection of full automation by operators.

Functional cultural differences included degree of regulation (high in U.S., whereas agencies in Europe are equally concerned with providing support); status of technical workers (high respect for master craftspeople in Europe); greater ethnic and cultural homogeneity in Europe; and differences in deployment and confidence in computerized display and control.

Rosenthal, I. *Organizational Analysis in High-hazard Production systems: An Academy/industry Dialogue*. Wharton Risk Management and Decision Process Center.

[Risk]

"Are there discoverable organizational 'Risk Factors' that would allow one to predict that one organization will manage a given hazard with fewer 'accidents' than another organization? The Wharton Risk Management and Decision Process Center believes there are and has developed an 'epidemiological' approach to study hypotheses about specific organizational risk factors."

Sagan, S. D. (1993) *The Limits of Safety*. Princeton: Princeton University Press.

[Evaluation, Safety]

Drawing primarily on issues surrounding nuclear weapon safety in the U.S., Sagan reviews the debate between high reliability organization (HRO) theory (which holds that certain organizations have shown themselves to be capable of continued safe operation, and studies their characteristics) and normal accident (NA) theory (which holds that serious accidents are to be expected in complex organizations). High reliability requires a high priority on safety from the leadership, substantial redundancy, an organizational culture that can prevent accidents (through decentralization, strong organizational culture, and continuous training), and learning (trial-and-error, anticipation, simulation). Normal accidents follow from high interactive complexity and tight coupling; organizations often have inconsistent preferences, unclear technologies, and fluid participation (thus a garbage can model). HRO theorists point to the lack of any significant nuclear weapons accidents in over 50 years of weaponry; NA theorists point to the many close calls. The two approaches converge in their focus on various desirable organizational characteristics; they diverge regarding the ease of obtaining and maintaining those conditions.

Salvendy, G. (1997) *Handbook of Human Factors and Ergonomics*. John Wiley: New York.

[Performance]

Edited collection of chapters surveying the field of human factors/ergonomics.

Schade, E., Shen, S.-H. & Mosleh, A. (1996) “Methodology for the analysis of human error probabilities.” *Transactions of the American Nuclear Society and the European Nuclear Society 1996 International Conference*, 75, 85-86.

[Modeling]

Briefly describes a PRA for Calvert Cliffs Nuclear Power Plant using Embrey's SLIM-MAUD and Hannaman *et al*.'s HCR model. Refers to a longer report.

Schinezel, G. (1999) “Human Performance Perspective in a Personal Safety Program.” 5th Annual Human Performance/Root Cause/Trending Workshop.

[Evaluation, Safety]

INPO identified industrial safety as an area needing improvement. Accident rates per 200,000 man-hours were increasing from 1993-97, even as the industry median was falling. Actions were focused on encouraging/reinforcing appropriate behaviors (and addressing inappropriate behaviors); employee inputs to address safety issues; review and safety procedures; communication/reinforcement of expectations; clarified safety vision and mission; and the COBRA safety program. COBRA (Changing Our Behavior Reduces Accidents) was intended to improve the safety culture through no-name, no-blame, peer-driven accountability without disciplinary action (work behavior observations, data entered in database to identify at-risk and appropriate behaviors). After 1 year, accident rate fell from 1.18 to 0.20 per 200,000 man-hours.

Schulman, P. C. (1997) “Reliability analysis and safety strategy in the chemical processing industry.” M.I.T. Conference on Organizational Processes in High Hazard Industries, http://stsfac.mit.edu/projects/risk/reports/intro.html.

[Evaluation, Safety]

This professor of government at Mills College worked on high-reliability organizations in nuclear power plant and air traffic control operations. The key reliability issue for most organizations is whether the benefits of increased reliability (improvement in production and efficiency) are worth the marginal costs. For high-hazard industries such as nuclear power or air traffic control, industry survival is precarious because some events are unendurable; reliability is non-marginalizable, and efficiency trade-offs are generally unacceptable. Trial-and-error learning is impractical when the first error is likely to be the last trial; it is difficult to get data to assess the reliability of precluded events. Examples from the chemical processing industry are considered. Notes that accident event analysis, as recommended by the Center for Chemical Process Safety, can impede learning by assuming that root causes

are failures of management systems; fear of regulatory punishment, criminal prosecution, and civil liability impede reporting. Notes that identifying a root cause in one event does not preclude the same event coming from a different root cause next time.

Schwartz, D. (1996) “Reducing The Human Error Contribution to Mishaps through Identification of Sequential Error Chains.”

[Evaluation, Human Error]

Suggests that because errors can progress along error chains toward a mishap, flight crews or others could be trained to recognize links in error chains and thereby interrupt them. Based on review of "more than 30 accidents and incidents," the author suggests "11 clues to identifying links in an error chain": ambiguity, fixation/preoccupation, confusion or an empty feeling, no one flying the aircraft, no one looking out of the window, use of an undocumented procedure, violating limitations or minimum operating standards, unresolved discrepancies, failure to meet targets, departure from standard operating procedures, and incomplete communications.

The Air Florida 90 crash in 1982 (into a Washington, DC, bridge) is discussed as an example. "Eight of the 11 links in the error chain were present and could have been recognised by this flight crew had they been trained in its use. Only one link is needed to break the chain..."

Sebok, A. L., Hallbert, B.P., Plott, B.M. & Nash, S.S. (1997) “Modeling Crew Behavior and Diagnoses in the Control Room.” IEEE Sixth Annual Human Factors Meeting.

[Modeling]

This study investigated the feasibility of using task network simulation to predict task performance and operator diagnoses in complex situations. Four crews of NPP operators participated in four process-disturbance scenarios (SGTR, LOFW, LOOP, and ISLOCA), each of which was modeled using MicroSaint. Three scenarios investigated operator task performance; the other scenario investigated operator diagnoses. Comparisons between simulation and empirical results revealed good predictive ability of the models. For task performance, models accurately predicted latencies between a critical event and appropriate response. The model of cognitive performance predicted many of the diagnoses the operators held during the scenario, as well as the shifts in diagnoses over time. These results indicate potential for using task network modeling to supplement empirical research and contribute to control room human-machine interface design.

There have been previous efforts to assess the applicability of task network modeling to nuclear industry research (Laughery and Persensky, 1994; Harrison, Zhai, and Milgram (1990). The findings suggest that task network modeling is a viable technique for evaluating operator performance, supporting human performance data, and predicting operator diagnoses. The simulations adequately predicted when operators would converge on certain types of diagnoses. Moreover, the model predicted nearly all types of diagnoses held by the operators.

Senders, J.W. (1999) “On Errors, Incidents and Accidents.” http://www.ergogero.com/onerror/onerrorhome.html

[Evaluation, Human Error]

This paper presents a brief history of the study of error in behavioral science, some useful ways to think and talk about error, and a brief introduction of some theoretical issues. The author argues that patient safety would be improved by abandoning the custom of blaming people who make errors and by gathering as much information as possible about what kinds of errors occur and with what frequencies and what probabilities.

Senders, J.W. & Moray, N.P. (1991) *Human Error, Cause, Prediction, and Reduction*. Lawrence Erlbaum Associates.

[Evaluation, Human Error]

Authors provide an overview of discussions from several conferences on human error that involved a “who's who” of error experts (e.g., Hollnagel, Loftus, Moray, Norman, Rasmussen, Reason, Rouse, Swain, Wagenaar, Woods, Wreathall, and others). Varying viewpoints are presented on most issues; "almost the only point of agreement at the conference was that it is fruitless to look to classifications based on neurological events" (p. 44).

Shaw, B. E. & Sanders, M. S. (1989) “Research to determine the frequency and cause of injury accidents in underground mining.” *Proceedings of the Human Factors Society 33rd Annual Meeting*, 1004-1008.

[Evaluation, Performance]

"The working hypotheses of this study were that not all accidents are caused by human error, and that when human error is a factor, other factors are often involved. Most accidents are the result of several interacting forces which significantly increase the probability of an accident." Using data from 20 mines and approximately 3.5 million labor hours, 338 accidents were investigated (all non-fatal MSHA-reportable accidents in the 29-month study period). A team of seven experts reviewed the reports and rated the importance of a set of 10 factors; the ratings were used to assign primary and secondary contributing factors. Management was implicated in 73% of the cases, work task in 75%, and a perceptual-cognitive-motor error by the injured employee in 93%. Management was implicated when basic equipment operation and mining safety knowledge or overall mining safety assurance were judged inadequate. Authors note that the other/miscellaneous factor was cited in over 30% of the cases, making it unlikely that a goal of zero accidents could ever be achieved.

Shen, S.-H., Smidts, C. & Mosleh, A. (1995) “Application of a model-based human error taxonomy to the analysis of reactor operating events.” *Proceedings of the American Nuclear Society*, 100-107.

[Modeling]

Discusses use of the IDA (information, diagnosis/decision, action) model.

Shen, S.-H., Smidts, C. & Mosleh, A. (1997) “A methodology for collection and analysis of human error data based on a cognitive model: IDA.” *Nuclear Engineering and Design*, 172 (1-2), 157-186.

[Modeling]

IDA (information, diagnosis/decision, action) is described as a model of cognition. It is used in conjunction with an operating crew behavior model for PRA. IDA includes a taxonomy of errors for each of its three stages. Forms have been developed for use during site investigations, prompting the interviewer to gather information relevant to the error categories and events used in IDA. The results of an investigation are then analyzed to determine the error root causes. Examples are given.

Skriver, J. & Flin, R. (1996) “Offshore Installation Emergencies: Situation Awareness, Decision Making and Human Error.” *Proceedings of the Human Factors and Ergonomics Society 40th Annual Meeting*, 1262.

[Evaluation, Human Error]

Abstract describes study using cognitive task analysis of 10 experienced offshore installation managers from an oil exploration and production company. Each participant was presented with paper-based emergency scenarios and asked for various types of information. Results showed these people drew on a sophisticated knowledge basis; errors could be due to inadequate situation awareness (misjudging time, risk, and resources available) and ineffective decision-making (rushing or being too hesitant in implementation).

Smart, K.L. (1997) “The Competitive Distinguisher: Developing and Maximizing Investments in Human Capital.” IEEE Sixth Annual Human Factors Meeting.

[Performance]

This paper discusses an organization’s intellectual resources as a form of capital similar to physical capital. The author discusses how to maximize the utilization of human or intellectual capital.

Smith, T. J. & Larson, T. L. (1991) "Integrating quality management and hazard management: A behavioral cybernetic perspective." *Proceedings of the Human Factors Society 35th Annual Meeting*, 903-907.

[Evaluation, Safety]

Notes that quality and safety are typically managed separately within most organizations, but suggests they should be integrated for mutual benefit. Data for 11 years from one firm (unspecified) were examined; it was found that across the period examined, the quality record (either as percent defective parts or manufacturing rework hours) fell along with the lost-time injury rate; this is said to suggest that "individual responsibility for working safety and for participating in hazard management... naturally carries over to careful workmanship."

Space Shuttle Independent Assessment Team. (2000) *Report to Associate Administrator*. National Aeronautics and Space Administration.

[Performance]

Two serious in-flight anomalies in 1999 led NASA to set up an independent team to review shuttle operations. One of the areas considered was human factors; the team conducted interviews and reviewed documentation, as well as collected questionnaire data on occupational stress from Marshall Space Flight Center. The team concluded that there were problems involving communication, adverse changes in work practices, increased work stress, physical strain, and a failure to incorporate human factors in decision processes.

Spiker, A. (1997) "A Process for Measuring the Usability of Plant Procedures." IEEE Sixth Annual Human Factors Meeting.

[Evaluation, Human Error, Methodology]

This paper discusses six problems that relate directly to the usability and level of detail in plant procedures: excessive page turning, difficult language, poor organization, too much detail, awkward formatting, and ill-conceived graphics. An NRC study found procedures to be contributing factors in more than 65% of the 1995 Licensee Event Reports (LERs); 40% of LERs involved inadequate procedures, with another 26% due to workers not following the procedure. This paper describes the results of an EPRI-sponsored project whose objective was to develop a systematic process for measuring how well plant workers can use task-based procedures. The Procedure Usability Measurement Process (PUMP) was designed to generate empirical data on procedure usability that could quantify procedure problems, diagnose specific procedure weaknesses, and guide remedial actions in the areas of procedure writing and training.

The PUMP process was pilot-tested at Zion Station in Illinois during 1996. For a complete description of the types and patterns of errors that were obtained on the two tests, the author refers the reader to the project's final report (referenced in this paper as Spiker *et al*., 1996). The authors planned to refine the PUMP methodology by revising the item difficulty scales, tightening the definitions of the ten functional elements, and developing more precise rules for scoring the items. Second, they plan to solicit the cooperation of two new host plants to serve as testbeds for applying the guidelines to develop additional PUMP tests (see EPRI TR-110175). Third, an analytical procedure will be developed that assesses the usability of a given procedure without the requirement for worker-in-the-loop testing.

Spurgin, A.J. (1994) "Some Thoughts on the Requirements for a Second Generation Human Reliability Assessment Process." *Proceedings of PSAM - II*, 54-1 to 54-5.

[Modeling]

This author states that HRA developments are needed. As knowledge of the field expands, this should be reflected in improved methods and increased awareness of the source of human errors. These improvements should not only be in quantification methods, but also in the representation of humans and organizations in risk models to help improve the safety of high-risk operations. The article goes on to discuss criticism against THERP, TRCs, and PRAs.

Stanton, N. & Baber, C. (1996) "A systems approach to human error identification." *Safety Science*, 22 (1-3), 215-228.

[Modeling, Evaluation]

Following an accident that is traced to "human error," it is common to implement discipline, training, automation, work checks, etc., but these efforts can be difficult to maintain, may miss insidious errors that reduce productivity without causing major errors, and do not address the human-technology interface. The paper is focused on methods to predict human error, by means of Human Error Identification (HEI): essentially, HIE is to analyze work, identify the points at which errors are likely to occur, and devise preventive strategies, typically following 7 steps: problem definition; analysis of performance shaping factors; task analysis; human error analysis; consequence analysis; error reduction strategies; and evaluation of recommendations

Notes that there are problems with quantitative predictions of errors (cites Reason, Hollnagel), and opts for qualitative methods; cites Kirwan (1992), who finds SHERPA is good on the grounds of comprehensiveness, consistency, theoretical validity, usefulness, resource usage, audit ability, and acceptability. HEI techniques mostly come from engineering approaches and do not deal adequately with the performance context of the cognitive bases for errors.

The authors promote qualitative modeling of human-machine systems. TAFEI (Task Analysis for Error Identification) uses hierarchical task analysis, state-space diagrams, and transition matrices to evaluate tasks.

Stanton, N. (1996) "*Human Factors in Nuclear Safety*." Bristol, PA: Taylor & Francis.

[Safety]

Divided into sections on organizational issues for design, interface design, personnel, and safety.

Steinbrink, J. (1997) "Human error plagues maintenance activities." http://www.impomag.com/397sr.htm

[Evaluation, Human Error]

The paper discusses error-likely conditions as causes of most accidents, near misses, and productivity problems in industry. However, situational errors are preventable. Error-likely situations are caused by a variety of missteps, including deficient procedures, poor communication, inadequate training, conflicting interests, misleading instrumentation, and poor design. The paper discusses how detailed written procedures may eliminate some of these causes.

Stewart, M.G. (1994) "Construction Error and Human Reliability for Structural Systems." *Proceedings of PSAM - II*, 100-7 to 100-12.

[Modeling]

This paper describes an attempt to use a HRA to simulate the effect of human error in construction tasks. The model uses a simple reinforced concrete beam as a test of the system. Estimates of system risk used in structural engineering are currently computed from probabilistic models that tend to exclude the influence of human error. Hence, the estimates of risk are not realistic. The author then applies the HRA to the construction of nuclear power plant structures.

Stockholm, G. W. Retson, D. (1997) "Effective root cause analysis for manufacturing performance improvement." *11th Annual International Maintenance Conference Proceedings*, http://stsfac.mit.edu/projects/risk/reports/intro.html.

[Evaluation, Performance]

Describes work at Shell Oil. Finds barriers to organizational change: People think they already know how to solve problems, that many problems have already been solved, and that training employees in failure analysis techniques leads to the employees actually applying the techniques. Manufacturing problems turn out to be more complex and interrelated than originally assumed—sometimes the root cause of a problem is found to exist 17-20 cause/effect levels below the observed effects and to contain multiple parallel failure paths. A variety of tools are available for problem identification, problem description, possible cause analysis, cause verification, and solution development. (Tables and figures missing are from this web-posted paper.)

Straeter, O. (2000) “Analysis and assessment of errors of commission in nuclear power plant settings.” *Proceedings of the IEA 2000/HFES 2000 Congress*, 3-851-854

[Evaluation, Human Error]

Discussion of errors of commission (EOCs), including mention of review of events at German nuclear power plants. EOCs are described as “a result of a mismatch between situational circumstances and internal representation of the world.” After considering cognitive aspects of EOCs, the author urges development of models for cognitive behavior.

Suzuki, T. & Takano, K. (1995) “Development of the technique for analysis and assessment of human error relating incidents - Development of Japanese version of HPES (J-HPES).” *Proceedings of the Topical Meeting on Safety of Nuclear Reactors*, American Nuclear Society, 834-840.

[Modeling]

The Human Factors Research Center (HFC) was established in 1987 within the Central Research Institute of Electric Power Industry (CRIEPI). This paper describes a project to introduce INPO's HPES to Japanese utilities "without inconveniences due to differences in work organizations, management methods, work practices, and equipment maintenance between US and Japan." It consists of an implementation procedure, evaluation forms, and evaluation techniques. An analysis support system was developed for use on personal computers.

Svensson, G.A. (1997) “Control Room Modernization from the Swedish Regulatory Perspective.” IEEE Sixth Annual Human Factors Meeting.

[Control Room]

Several Swedish nuclear power plants are modernizing instrumentation and control systems (I&C systems), including the control room. Single systems and parts have been exchanged to fix acute problems. This approach threatened to result in several different interfaces in the control room.

The modernization programs are extended over a long period, approximately 10 years, necessitating careful advance planning and control. One essential part of the more proactive top-down approach taken is to include into the program a preparatory phase of analysis and investigation in order to lay down the rules, requirements, and implementation strategy controlling the future single projects. A checklist was being developed in order to support desktop reviews of the project handbooks. It is expected that the checklist also can be used in reviews of other similar documents controlling later phases of the I&C and control room modernization programs.

Swain, A.D. & Guttmann, H.E. (1983) *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications*. U.S. Nuclear Regulatory Commission, NUREG/CR - 1278 - F.

[Evaluation, Performance, Modeling]

The standard handbook for human reliability analysis in nuclear power plants to assist in evaluation of performance-shaping factors (PSFs) for PRAs. "The scarcity of objective and quantitative data on human performance in NPPs is a serious limitation. Most of the HEPs in this Handbook are what we call derived data. In some cases, they are extrapolations from performance measures, which may be only marginally related. In other cases the HEPs represent our best judgment...” A final point, which some may consider a limitation, is that the Handbook does not deal with malevolent behavior. Various PSFs are listed and discussed in Chapter 3, including external (situational, task/equipment, and job task instruction factors), internal (organismic or personal characteristics, motivation, emotional state), and stressors (physiological such as fatigue, psychological such as task load or reinforcement).

Swanson, R.N. (1999) “The ‘Runaway filter.’” Performance Management Initiatives, Inc., Fifth Annual Human Performance, Root Cause, and Trending Workshop.

[Evaluation, Methodology, Modeling]

This paper summarizes a partial event investigation performed for the "Fifth Annual Human Performance, Root Cause, and Trending Workshop" held in Kansas City, Missouri, May 24-28, 1999 in preparation for a panel discussion. Based on information about an actual generating station event provided by the Workshop sponsor, panel members individually evaluated the event using different event investigation/root cause analysis approaches. These evaluations were summarized and compared during the panel discussion. The investigation summarized in the paper was limited to the "traditional" tools of Event & Causal Factor Charting and Barrier Analysis. The event itself was a loss of physical control of a radioactive pre-filter during transport from the worksite to the designated storage location. The event description from the workshop sponsor was sufficient for the author to identify a number of inappropriate actions and a number of failed barriers.

Szameitat, S. (2000) “Using collaborative information technology learning more about safety-critical events.” *Proceedings of the IEA 2000/HFES 2000 Congress*, 4-391-394.

[Evaluation, Safety]

Describes use of computer-mediated communication for event analysis teams. This is intended to improve use of accident and near-miss reporting systems (ASMASs) through asynchronous information exchange. A simulation study with nontechnical participants found computer-mediated communication sped up information exchange.

Takashima, S. & Furuta, T. (1992) “Analysis and evaluation of human error events in nuclear power plants.” *Proceedings of the 8th Pacific Basin Nuclear Conference*, 3L-1 to 3L-4.

[Evaluation, Human Error]

Electric utilities in Japan are required to report incidents and failures from commercial nuclear power plants; those classified as related to facility malfunctions have been declining, whereas those due to human error are remaining constant. Human errors are analyzed and classified according to content, mode, mechanism, causes, preventive measures, etc. Several guidance documents have been prepared. It was planned to establish a database of the error data.

Tamuz, M. (1980) “Near Accident Reporting Systems: Exploring Methods of Monitoring Potential Dangers.” National Research Council.

[Evaluation, Safety]

Slides summarize the value of safety information, effects of information collection conditions (e.g., whether punitive, mandatory, or confidential), and suggestions for new approaches such as automated performance surveillance.

Tamuz, M. (1997) “Near miss analysis.” M.I.T. Conference on Organizational Processes in High Hazard Industries, http://stsfac.mit.edu/projects/risk/reports/intro.html.

[Evaluation, Methodology]

Recommends studying near accidents. Organizations have trouble learning from accidents because they are important (fear of liability, fear of punishment), complex (hard to fully understand because so many things may combine and go wrong), and rare. Near accidents can provide information about how a system works and what may go wrong. Notes that incentive systems can impede collection of near-miss data; several citations are given. Minarick (1990) developed procedures to identify accident precursors using information about potentially dangerous events. Oster *et al*. found that near accidents in air transport were not strongly correlated with mid-air collisions. Perron & Friedlander suggest that downsizing can disrupt safety efforts because the staff is smaller and less qualified/experienced; using contract workers puts additional strains on safety. Syncrude (in Canada) reports that it has a no-fault incident reporting system, currently being automated.

Tamuz, M. (1994) “Developing Organizational Safety Information Systems for Monitoring Potential Dangers.” *Proceedings of PSAM - II*, 71-7 to 71-12.

[Evaluation, Database]

Discussion of collecting and learning from near-accident events to supplement what can be learned in high-risk environments "where disastrous accidents rarely occur and the threat of disastrous consequences hinders trial-and-error learning." Echoes Van der Schaaf's advice to use near-accident information solely for analysis when the organization wants to learn about risk, rather than using the same data for policing behavior; this requires immunity-based incentives. Punishing of reported rule violations yields under-reporting of near accidents, as in the FAA's monitoring of near mid-air collisions: with immunity, the number or reports increased from 559 in 1965 to 2230 in 1968, but then fell to 231 when immunity was retracted in 1972. Disciplinary action also tends to produce biased information and undermined trust.

Tasset, D. (1998) “N4 series: Safety assessment of human factor aspects in the computerized control room.” *Revue Generale Nucleaire International Edition*, A, 15-20.

[Safety]

Describes development of the new control rooms for EDF, from submitting general characteristics to the safety authority in 1980, through first trials in 1990, to full operation in 1996. Two primary issues are discussed: Could the unit be operated acceptably, especially in accident situations? Could it be operated acceptably in the event of failure of the computer system?

Taylor-Adams, S. E. (1994) “Development of a human error taxonomy for use with a human error data base.” In S. A. Robertson (Ed.), *Contemporary Ergonomics 1994*, Taylor & Francis: London, 329-334.

[Modeling]

Describes work on CORE-DATA (see also Kirwan *et al*., 1997). For the Psychological Error Mechanism taxonomy, a set of 58 PEMs (psychological error mechanisms) was selected from various taxonomies; these were reduced to 32 after hierarchical organization. These were then compared to three models of human behavior: Wicken's Information Processing Model, Rasmussen's Simplified SRK [skill-rule-knowledge] model, and Rasmussen's Step Ladder. Next, the set was changed to 20 main PEMs and 26 sub-PEMs. Aspects of the three models of human behavior were combined into a composite model.

Taylor-Adams, S.E. (1994) “Development of a Human Error Data Bank.” *Proceedings of PSAM - II*.

[Evaluation, Modeling]

The AEOD staff presented a summary report of its programs for risk-based analysis of reactor operating experience. Staff are convinced that careful review of operating experience is the most applicable source of information that the NRC and the industry have to validate system reliability analysis models and predictions, and such review is the best source of data for future use. The resources to perform a full-scope analysis are not currently available.

Thomadsen, B. Caldwell, B, Leammrich, P., Stitt, J., McConley, R. (1999) “A Tool to Assist in the Assessment of Human Performance Failures.” *CHPCS Sixth Annual Workshop Proceedings, Human Performance: Bridging the Gap Between Research and Practice*.

[Modeling]

Data on a set of occurrences requires a large number of incidents to see patterns that point to weak spots in a system. This presentation demonstrates a software tool developed to assist in managing and analyzing such data. During the process of investigating mistakes made throughout the U.S. during medical treatments using radioactive materials, the data were fit into three models for human performance—van der Schaaf (PRISMA/SMART), Rasmussen, and Caldwell and Kapp (SCOPE)—with the hope of selecting the best tool. Results showed that each model looked at the parameters of the event differently, and it provided complementary insights. The database tool, while developed to address incidents in radiation therapy, could with minor variations apply equally well to other settings. The basic tracking and analysis approach remains the same.

Thompson, C. M., Foresster, J. A., Cooper, S. E., Kloaczkowski, A. M., Bley, D. C. & Wreathall, J. (1997) “The application of ATHEANA: A Technique for Human Error Analysis.” *Proceedings of the 1997 IEEE Sixth Conference on Human Factors and Power Plants*, 9-13 to 9-17.

[Modeling]

Event analyses of nuclear power plant accidents and incidents show that operational events "typically involve a combination of complicating factors which are not addressed in current PRAs," such as multiple equipment failures and unavailabilities, instrumentation problems, and plant conditions not covered by procedures. ATHEANA is based on the idea that human errors occur from combinations of influences that trigger error mechanisms, not necessarily from bad behavior; hence the inter-relations between error mechanisms, plant conditions, and performance-shaping factors must be studied. The proposed framework has been used in several NUREG retrospective event analyses. Human information processing is divided into situation assessment, response planning, response implementation, and monitoring/detection. The basis steps in applying ATHEANA involve preparation, identification of human failure events (HFEs) and unsafe acts, identification of potential causes of unsafe acts, quantification of human failure events, and incorporation of these HFEs into a PRA.

Thompson, R. C., Hilton, T. F. & Witt, L. A. (1998) “Where the safety rubber meets the shop floor: A confirmatory model of management influence on workplace safety.” *Journal of Safety Research*, 29 (1), 15-24.

[Evaluation, Safety]

Notes that it is clear that management actions can affect employee perceptions of safety priorities and can contribute to an organization's work climate, but that there is little empirical research on how managers can promote workplace safety. Cohen and others have shown that management involvement and support are significant for establishing and maintaining a safe workplace; several have suggested that inconsistencies can adversely affect worker perceptions of safety commitment and priority, and that supervisor unfairness can decrease compliance with safety procedures. Accident rate data is not necessarily useful for studying workplace safety for four reasons: restricted variance (because accidents are so rare), not always under the control of the people involved, inconsistent recording (biases for under- or over-reporting), and biases towards reporting more severe incidents. Self-reporting of safety behaviors and perceived workplace safety is proposed as an alternative. Path analysis of earlier results showed that organizational politics, goal congruence, and supervisor fairness contributed to perceived management support for safety, which in turn determined perceived safety conditions at the FAA Logistics Center (warehousing, a fabrication shop for parts, and an administrative office). A revised study found that organizational politics and supervisor fairness contributed to manager and supervisor support for safety, which determined safety conditions and reported safety compliance (all self-reporting).

Tochihara, Y., Shiroki, K., Ito, H., Fujiwara, A., Horie, A. (1996) “Activities on Human Errors Prevention in Kashiwazaski Kariwa Nuclear Power Station.” IERE Workshop, Human Factors in Nuclear Power Plants

[Evaluation, Human Error]

The authors set up a "Human Factors Study Committee" to consider measures to prevent human errors. They divided the goals of this activity into five stages and promoted it step by step. They used HIYARI-HATTO cases, which are experiences of operators in which they came close to having human-error-related incidents. This activity, which has been carried out since 1994, was still going on at the time of publication. The paper describes the progress of the activity.

Trager, E. A. (1997) “The Human Performance Event Data Base (HPED).” *Proceedings of the 1997 IEEE Sixth Conference on Human Factors and Power Plants*, 14-10.

[Evaluation, Database]

Briefly describes ongoing development of a database by the NRC "for information on human performance during operating events. ... The HPED currently includes data on events described in augmented inspection team (AIT) reports from 1990 through 1996, 20 AEOD human performance studies that were performed from 1990 through 1993, and recent NRR special team inspections. The database also includes data from the licensee event reports that were prepared for these events."

Trimpop, R.M. & Wilde, G.J.S. (1994) *Challenges to Accident Prevention, The issue of risk compensation behavior*. SIYX.

[Risk]

Presentations from conference sessions in 1989 and 1991 devoted to risk compensation and traffic safety. The general conclusion supported here is that behavioral adaptation exists and affects the safety benefits of road safety programs. Ruppert notes that risk homeostasis has not been examined in industry and suggests considerable work is needed.

Ujita, H. (1985) "Human error classification and analysis in nuclear power plants." *Journal of Nuclear Science and Technology*, 22 (6), 496-498.

[Evaluation, Human Error]

Notes that LERs do not provide adequate information for a detailed analysis of human errors such as in Rasmussen *et al*. (1981). For this project, a set of reports was analyzed for 413 occurrences at boiling water reactors in 1979 in the U.S. (data from NRC). Errors were classified by task type, error cause (11 categories), and how error was detected. Findings indicate 42% of human errors occurred in the design/construction phase, 33% in maintenance, 25% in operation. Two-way comparisons are presented.

U.S. Chemical Safety and Hazard Investigation Board. (2001) *Investigation Report, Refinery Fire Incident, Tosco Avon Refinery*. Report No. 99-014-I-CA.

[Safety, Evaluation]

This investigation report examines the refinery fire incident that occurred on February 23, 1999, in the crude unit at the Tosco Corporation Avon refinery in Martinez, California. This report identifies the root and contributing causes of the incident and makes recommendations for control of hazardous nonroutine maintenance, management oversight and accountability, management of change, and corrosion control.

U.S. Department of Energy. (1992) *Root Cause Analysis Guidance Document*. DOE-NE-STD-1004-92, February.

[Modeling]

Guide for root cause analysis as specified by DOE Order 5000.3A, Occurrence Reporting and Processing of Operations Information. Describes techniques for root cause analysis: Events and Causal Factor Analysis, Change Analysis, Barrier Analysis, MORT and Mini-MORT (management oversight and risk tree analysis), human performance evaluation, and Kpener-Tregoe Problem Solving and Decision Making, along with a flow chart for when to use each technique. A set of cause codes is provided (7 categories, 32 total codes), as are examples of each of the analysis techniques.

Van Cott, H. P. (1997) “Were the control room reviews worth it?” *Proceedings of the 1997 IEEE Sixth Conference on Human Factors and Power Plants*, 3-33 to 3-34.

[Control room]

Author has heard that costs for correcting human engineering discrepancies in control rooms cost from $1.5 to $3 million per unit. It is hard to find an objective measure to evaluate effectiveness, because many other changes were made by the industry during and after the control room reviews (e.g., improvements in emergency response procedures, enhanced operator training, extensive use of simulators). In addition, some reporting systems and measures had been changed, making trending difficult to interpret.

Van der Schaaf, T.W. “Incident reporting and analysis in maintenance.”

[Evaluation, Safety]

Urges use of near-accident reporting for maintenance activity. A pilot study of 15 near misses in a large chemical plant resulted in 54 root cause failure factors, with 43% technical, 30% human, and 24% organizational.

Van der Schaaf, T.W. PRISMA.

[Modeling, Evaluation]

Provides description of the Eindhoven classification model of system failure and the classification matrix that separates potential corrective actions into changes to equipment, procedures, information/communication, training, and motivation. For each causal factor, there is a proposed preferred type of action, e.g., an equipment change for a technical engineering factor and an information change for a problem of human behavior related to knowledge of system status. The intent is that classifying a near miss leads to a recommendation for appropriate action.

Van der Schaaf, T. W. (1999) “Incident Reporting and Analysis Systems: Theory and Practice.” *CHPCS Sixth Annual Workshop Proceedings, Human Performance: Bridging the Gap Between Research and Practice*.

[Evaluation, Modeling]

Describes a near miss as the result of a failure (human, technical, or organizational) creating a dangerous situation with inadequate defenses but for which recovery is adequate to prevent an accident. Near misses are more visible than behavioral acts and more frequent than accidents. Benefits of near-miss reporting include models of precursors, monitoring of safety, and alertness for unsafe conditions. Describes PRISMA (Prevention and Recovery System for Monitoring and Analysis). Uses root cause analyses; gives a breakdown for 563 records, with the Eindhoven classification model for system failure: Technical (engineering, construction, or materials), Organizational (operating procedures or management priorities),

and Human Behavior (knowledge: system status or goal; rule: license, permit, coordination, check, planning, equipment/information; skills: controlled, whole-body).

Van Hemel, S. B., Connelly, E. M. & Haas, P. M. (1991) "Management and organizational indicators of process safety." *Proceedings of the Human Factors Society 35th Annual Meeting*, 908-912.

[Evaluation, Safety]

In work sponsored by the NRC to identify leading indicators for nuclear power plants, three case studies from the chemical industry were examined. In the first, at a company with a Total Quality Management system, auditors trained by the company safety department rated 74 plants; process safety ratings were found to be significantly related to process safety incident frequency, which "suggests that at least some of the indicators used in that rating system may be leading indicators of plant process safety." A second company used a Safe Acts Index at a large plant, with employees observed daily and the data tabulated weekly; the number of injuries was found to decrease significantly once the Safe Acts Index had risen. In a plant with 14 years of data available, injuries were found to be correlated with various process safety measures, such as the occurrence of high-potential incidents and poor housekeeping. The authors suggest consideration of Safe Acts Index, audit-type indicators, and organizational culture indicators for the NRC.

Van Middlesworth, G. (1999) "Establishing a Strong Safety Culture." Duane Arnold Energy Center.

[Evaluation, Performance]

Plant manager from Duane Arnold suggests in these slides that a dramatic crisis is needed to bring current culture into question. Conditions for change include top management commitment and involvement, support of employees who espouse the new values, enforcement of new rules of norms, replacement of stories/symbols/rituals, redesign of social process, change reward system, use of transfers and job rotation to shake current subcultures, and development of consensus-building through employee participation and trust. Key goals are excellent NRC and INPO performance and excellent public trust; in addition, low costs and high production are important objectives.

Varonen, U. & Mattila, M. (2000). "The safety climate and its relationship to safety practices, safety of the work environment and occupational accidents in eight wood-processing companies." *Accident Analysis and Prevention*, 32, 761-769.

[Evaluation, Safety]

Cites Seppala (1992) study of Finnish industry that found safety climate depended on organizational responsibility, worker concern about safety, worker indifference with regard to safety, and the level of safety precautions in the company. For the present study, Finnish wood processing companies were chosen such that four had clearly below-average accident rates (for the industry) and four had high accident rates, in matched pairs (4 sawmills, 2 plywood factories, 2 parquet factories). Workers filled out questionnaires (60-70% participation) involving safety climate (5-point ratings for 18 questions about daily safety practices/attitudes/motivation and for 14 about safety precautions) and company safety practices (4-point ratings for 22 variables). In addition, workers rated the safety level of the work environment (49 checklists: 27 for woodworking machines, 5 for conveyors, 5 for lifting and transferring machines, and 12 others; each checklist had a series of items to be rated as correct/incorrect/irrelevant). Work accident data for 6 years were obtained and reviewed. Factor analysis produced three main factors for safety climate (generalized as organizational responsibility, workers' safety attitude, and supervision of safety) and one for company safety precautions. When these four factors were compared with three factors for company safety practices (safety activities, anticipation of hazards, and safety training), only one correlation was significant (company safety precautions with anticipation of hazards). Organizational responsibility and company safety precautions were significantly correlated with accident rate. The low-accident-rate companies had higher scores on organizational responsibility and company safety precautions.

Voss, T. J. (1998) “Current human factors standards development efforts within IEEE.” *Proceedings of the 1997 IEEE Sixth Conference on Human Factors and Power Plants*, 3-1 to 3-6.

[Standard, Control Room, Modeling]

IEEE standards include the Overview Document Human Factors Analysis Standard IEEE Std 1023-1988 (reaffirmed 1995, revision in progress), Human Performance Measurement Standard IEEE Std 845-1988 (revision in progress), Human Reliability Analysis Standard IEEE Std 1082 (draft, ballot in progress), and Computer Generated Display Standard IEEE Std 1289 (draft, ballot in progress). The measurement standard is the IEEE Guide to Evaluation of Man-Machine Performance in Nuclear Power Generating Station Control Rooms and Other Peripheries, to be renamed as the IEEE Guide for the Evaluation of Human-System Performance in Nuclear Power Generating Stations. The HRA standard does not specify a specific method.

Wagenaar, W. A. & Groeneweg, J. (1988) “Accidents at sea: Multiple causes and impossible consequences.” In E. Hollnagel, G. Mancini & D. D. Woods (Eds.) *Cognitive Engineering in Complex Dynamic Worlds*. San Diego: Academic Press.

[Evaluation, Human Error]

Authors reviewed 100 reports of accidents at sea from the Dutch Shipping Council; 96 were found to have human error among the causes identified, always as necessary conditions: "In 96 out of 100 cases the people involved could and should have prevented the accident, but did not." Many accidents are "impossible … Accidents appear to be the result of highly likely complex coincidences which could rarely be foreseen by the people involved; the unpredictability is caused by the large number of causes and by the spread of information over participants ... Many accidents are outrageous and bizarre, not because people take outrageous risks, but because people assume that the bizarre will not occur … Errors do not look like errors at the time they are perpetrated, and the accidents that are caused by them look impossible beforehand. Still human error is the most promising target for those who

want to reduce accidents. However, telling people to change their behavior when facing accidents will not help, because they will rarely believe they are facing accidents."

Weikert, C. & Johansson, C. R. (1999) “Analyzing incident reports for factors contributing to air traffic control related accidents.” *Proceedings of the Human Factors and Ergonomics Society 43rd Annual Meeting*, 1075-1079.

[Evaluation, Performance]

Used 36 incident investigation reports based on self-reporting from two Swedish Air Traffic Control Centers. Two judges identified contributing factors (lack of concentration, methodology, handover, lack of training, phraseology) and background factors (site, traffic intensity, total time as controller, ambition level, time since first checked out in sector, shift). Lack of concentration and handover were the most commonly cited contributing factors; incidents were more common in light/medium conditions and in the morning.

Welch, N. (1997) “Defining the "human" in human error risk assessment.” *Proceedings of the Human Factors and Ergonomics Society 41st Annual Meeting*, 1390.

[Evaluation, Human Error]

This poster argues that human error has not been fully defined yet, tending to ignore the affective elements that are part of human reaction.

Wells, G. & Phang, C. (1994) “Concept Safety Review of a Sociotechnical System.” *Proceedings of PSAM - II*, 47-19 to 47-24.

[Evaluation, Safety]

Recommends a review for a new plant at the conceptual or preliminary engineering stage, involving discussion of subsystems and with a list of safety-related keywords or topics to address for each subsystem (e.g., for procedures, consider topics such as working practices, quality control, and incident reporting). Three stages of hazard identification involve Concept Hazard Analysis, Preliminary Hazard Analysis, and HAZOP. The approach can also be used in an existing facility, such as in reviewing a near miss or incident. Gives the example of a refinery fire; claims that a group of safety specialists using this procedure can come up with a list of potential root causes or latent problems quickly.

Wenner, C. & Drury, C. G. (1996) “Active and latent failures in aircraft ground damage incidents.” *Proceedings of the Human Factors and Ergonomics Society 40th Annual Meeting*, 796-800.

[Evaluation, Methodology]

Notes that it is necessary to predict, identify, and remedy latent failures in order to reduce incidents. Describes a project in which 130 Ground Damage Incident reports from mechanics were analyzed. These were sorted into hazard patterns. Then, the incidence of latent failures

was examined in relation to these patterns. Presumably managers can then prioritize interventions based on the associated costs as well as the importance of the patterns.

Westrum, Ron. (1999) *Safety culture indicators*.

[Evaluation, Safety]

Author says an organization has a strong safety culture when the following elements are present:

- There is a strong organizational emphasis on safety.
- The culture has a high "collective efficacy"—a high degree of cooperation and cohesiveness
- The culture encourages effective and free-flowing communication
- There is clear mapping of its safety state and, thus, its problems.
- There is a learning orientation—an ability to learn from mistakes and to be proactive about fixing situations that have not yet (but could) cause performance problems.

Excerpted descriptions of these characteristics are provided below.

Organizational Safety Emphasis. Although it seems obvious, the emphasis on safety is one of the key elements in a strong safety culture. An organization can be quite "effective" by a different set of criteria without being oriented to safety. Indicators of a safety emphasis include

- High visibility of safety-positive statements in the organization's formal communications, such as the corporate goals, the mission statement, annual reports, etc.;
- The prominence of safety in performance indicators: setting and enforcing ambitious safety goals;
- The corporate level to which the Safety manager reports and the power given to decisions made by the Safety department;
- The weight which safety performance is given in evaluations of operating personnel; and
- Innovative or path-breaking efforts used as benchmark by others.

Collective Efficacy. This variable reflects the degree to which the organization as a whole sees itself as a team and feels it is pursuing a common goal. "Alignment" is another word for the same phenomenon. This includes both the identification of company personnel with the rest of the company and also the sense of empowerment that such identification will yield. Indicators include

- The perception that "we are all on the same team." (alignment);
- The perception that management "walks the talk";
- A perception that requests for assistance will be answered;

– A sense that the organization has the capability to improve itself; and

– Rapid response to problems without red tape, excuses, or "we will study the problem"; "latent pathogens" are rapidly fixed when identified.

Free-Flowing and Effective Communications. The key is a communication effort that responds to the needs of safety rather than internal pressures, hierarchical needs, or rule-oriented practices. Communication takes place rapidly and without constraints imposed by conflicts, fear, or overwork. Indicators include

– A belief that communications from management are honest and timely;

– A feeling that you can "say what you think" without fear of reprisal;

– Telling the truth is more important than looking good;

– A willingness to cross organizational boundaries if necessary to inform someone of a hazard or a situation that requires action;

– "Latent pathogens" are rapidly spotted via "pop-out" systems; and

– Whistle-blowing results in fixing the problem, not fixing the whistle- blower.

Clear Mapping of Safety Situation. Organizations differ greatly in regard to having a clear map of their safety problems. Some organizations provide a system-wide audit on a regular basis. Some have audits only as a response to external prodding. Mapping provides indications of hazard as well as focus for improvements. Elements of safety mapping include

– Regular internal audit of safety conditions throughout the entire system;

– Visibility of these internal audits to managers and employees alike;

– Regular external audits to check the internal ones; and

– Special studies and audits are integrated with periodic audits and used as a cross-check.

Organizational Learning. Organizational learning includes a complex of activities that take into account not only past experience but also the experience of others. The organization learns not only from doing but also from thinking ahead about problems not yet encountered. Indicators of effective organizational learning are

– Regular debriefs after operational irregularities;

– Improving the system based on past operating problems, recommendations based on internal or external studies, and proactive response to anticipated problems;

– Not experiencing the same failure a second time;

– Intelligent and customized use of innovations pioneered by others; and

– Tasking key individuals with mission to provide improved corporate learning.

Wiegmann, D. A., Rich. A. M. & Shappell, S. A. (2000) *Human error and accident causation theories, frameworks and analytical techniques: An annotated bibliography*. Aviation Research Lab, Institute of Aviation, University of Illinois at Urbana-Champaign. Technical Report ARL-00-12/FAA-00-7. (http://www.aviation.uiuc.edu/new/html/ARL/TechPdf/00-12.pdf).

[Human Error]

Purpose of this review is to summarize research and technical articles that either directly present a specific human error or accident analysis system or that use error frameworks in analyzing human performance data within a specific context or task. The hope is that this review of the literature will provide practitioners with a starting point for identifying error analysis and accident investigation schemes that will best suit their individual or organizational needs.

Wiener, E.L., Kanki, B.G., Helmreich, R.L. (1993) *Cockpit Resource Management*. San Diego: Academic Press.

[Performance]

Most evaluations of CRM and LOFT (line-oriented flight training) deal with attitude changes; "as we have noted, the number of accidents involving crews with formal training in CRM and LOFT is too small to draw any statistical inferences regarding the role of these experiences in helping crews cope with serious emergency situations" (p. 36). There is evidence from observations that crew behavior improves after introduction of CRM and LOFT; however, there is also evidence that "a small but significant percentage of participants 'boomerang' or reject CRM training."

Wildavsky, A. (1988) *Searching for Safety*. New Brunswick: Transaction Books.

[Evaluation, Safety]

Basic premise: "there can be no safety without risk." Uncertainty about risk cannot be reduced to zero, and most acts can potentially lead to either safety or harm depending on the circumstances. It is necessary in general to take chances in order to learn about risk and to remain flexible. The final chapter is entitled "The secret of safety lies in danger": Safety is seen as a process, a balancing act, testing new approaches that allow for improvement rather than staying with a rigid status quo. Cites examples where excessive regulation or excessive installation of safety devices can compromise safety.

Wilde, G.J.S. (1994) *Target Risk*. Toronto: PDE Publications.

[Risk]

Survey of Wilde's theory of risk homeostasis, with some supporting studies. Evidence cited is discouraging with respect to the traffic safety value of intervention by educational campaigns, engineering changes, or enforcement.

Williams, J. H., & Geller, E. S. (2000) "Behavior-based intervention for occupational safety: Critical impact of social comparison feedback." *Journal of Safety Research*, 31(3), 135-142.

[Evaluation, Safety]

A study of employees in a bottling plant found that providing social comparison feedback (information about an individual's observed safety behavior as compared with their group) was associated with significant increase in safe behavior scores, especially when the feedback addressed specific behaviors rather than just a global safety score.

Wilpert, B. & Miller, R. (1999). *Organizational factors: Their definition and influence on nuclear safety (ORFA). Report on needs and methods*. Commission of the European Communities, Fourth Framework Programme on Nuclear Fission Safety, AMM-ORFA(99)-R03.

[Safety]

This report addresses nuclear safety on a broad basis; it may serve as a guide for research on how to approach organizational factors as a component of nuclear safety in future.

Woodyard, C. "Morale low in job with little margin for error." *USA Today*.

[Evaluation, Performance]

Newspaper account of a survey of FAA employees; "the findings raise the possibility of a link between poor morale and job performance in an agency trying to cope with a 16% increase in air-traffic control errors the past 10 months, compared with the same period last year." Results indicate that only 20% of employees think FAA top management cares about them, 60% think management doesn't encourage hard work, 55% think management doesn't adequately address conflicts, and 75% don't think the findings will be used to improve conditions. One controller commented that the FAA is top-heavy with management.

Wreathall, J. & Jones, L. (2000) "Leading indicators of human performance - The story so far." Presented at the 6th Annual Human Performance / Root Cause / Trending Conference, Philadelphia.

[Human performance]

Summarizes work through June 2000 on EPRI Nuclear work to develop leading indicators (see EPRI, 1999b, 2000b). This includes the literature and model review that led to the identification of seven recurrent themes in human performance, as well as development and testing of a questionnaire tool for worker feedback on organization and workplace factors.

Wreathall, J., Schurman, D.L. & Anderson, N. (1991) "An Observation on Human Performance and Safety: the Onion Model of Human Performance Influence factors." *Probabilistic Safety Assessment & Management*, 1, 25-30.

[Modeling]

Risk management involves the interaction of risk maker (the people or operations that carry out a potentially risky activity such as generating electricity), risk assessor, and risk manager. The risk maker must maintain adequate competence, the risk assessor must have adequate awareness, and the risk manager needs adequate commitment of resources and power.

An incident is said to involve specific tokens/unique factors such as mis-selected switches. Those in turn are caused or permitted by types, which are higher-level factors such as a decision to ignore identified human factors deficiencies. Tokens are found at the sharp end, whereas types are associated with management or supervisory activity.

The Onion Model is described as an outgrowth from Lewinian Field Theory: "a series of englobing fields ... mutually interacting .. a general identify at each level." From outside inward, the levels for a corporate entity in the Onion Model are as follows:

0. Corporate environment (e.g. regulations, public relations)

1. Corporate level (e.g. size, goal structure, management structure)

2. Plant/site

3. Program/division

4. Work unit

5. Worker

Wright, S. J., Packebush, S. J. & Mitta, D. A. (1993) "Software interface evaluation: Modeling of human error." *Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting*, 453-455.

[Modeling]

The GEMS framework (slips at the skill level, mistakes at the rule level, and mistakes at the knowledge level, especially by beginners) was used to characterize errors made by students using a MacIntosh graphics package for the first time. Most errors were made in the first several trials; knowledge-based errors were much more frequent than rule-based errors. There was a significant tool (e.g., circle, line, polygon) by error type interaction.

Wyon, D.P. (1998) "The effects of nutrition on human performance in school and at work." Workshop on "Expanding Human Performance Envelopes: Tools for Industry."

[Evaluation, Performance]

Summarizes studies showing better performance following a breakfast or lunch than after having only a light snack. Concludes that "subsidizing breakfast and lunch may be a cost-effective means of improving the productivity of adults and the school performance of children."

Xiao, Y., Mackenzie, C.F., Patey, R. & LOTAS Group (1998) “Team coordination and breakdowns in a real-life stressful environment.” *Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting*.

[Evaluation]

Analysis was performed of 16 video recordings of actual trauma patient resuscitations; qualitative findings are reported. "Considering the uncertainty and task difficulties involved in trauma patient resuscitation, the team coordination was adequate in the majority of the cases we analyzed. However, breakdowns in team coordination were observed in a number of crisis situations..." due to the pressure to seek alternative solutions, the unexpected nonroutine procedures initiated, and the diffusion of responsibility. "When team coordination broke down, it often occurred in situations where there was a lack of explicit communication."

Yoon, W. C., Lee, Y. H. & Kim, Y. S. (1996) “A model-based and computer-aided approach to analysis of human errors in nuclear power plants.” *Reliability Engineering and System Safety*, 51, 43-52.

[Modeling]

Notes that human error causes can be identified with models or taxonomies, such as GEMS, HEA, and Rasmussen's Human Malfunction Taxonomy, whereas systematic analysis of incidents are used as feedback in the industry to improve plant design and training, with techniques such as INPO's HPES (Human Performance Enhancement System) or the NRC's HPIP (Human Performance Investigation Program). This paper describes development of K-HPES for Korean plants, including a computerized support system for analysis.

Yoshino, K. (1996) “Practical Development of Human Behavior Prediction System (KY-ASSIST).” IERE Workshop, Human Factors in Nuclear Power Plants.

[Modeling]

This paper describes development and applicability of the human error and behavior prediction system or the Error Prediction System (HEBPS), which is capable of predicting rates of occurrence of errors from inputs of performance-shaping factors and provides systematic information for effective measures and safety education to be taken on the site. Example forms are included.

Yoshino, K. & Inoue, K. (1993) “Practical development of Human Errors and Behavior Prediction System (HEBPS) from the viewpoint of psychological and statistical methods.” In P. Kafka & J. Wolf (Eds.), *Safety and Reliability Assessment - An Integral Approach*, Elsevier: Amsterdam, 949-959.

[Modeling]

An error causality model includes 52 PSFs (performance-shaping factors), along with error factors (which trigger errors under the influence of PSFs), error-causing factors (which lead to errors under the influence of error factors), and errors. PSFs are weighted (0, .1, .45, or .9) and sorted in five categories: man-machine interface, internal to workers, work characteristics, organizations, and external relationship. Inquiry forms were developed to determine influences of various PSFs and factors. Based on survey results from nuclear power plant experts, errors in judgment and decision-making were judged to have the greatest influence, whereas errors of sensory origin or pattern recognition had least.

Young, T. “The role of sleep disorders in behavioral morbidity.”

[Performance, Evaluation]

This is an outline of a lecture discussing the effects of abnormal or inadequate sleep on work performance.

Yow, A. B., & Engh, T. H. (1997) “Discrete Event Simulation of Operator Interaction with an Alarm System.” *IEEE Sixth Annual Human Factors Meeting*, 7-24 to 7-29.

[Performance]

Discrete event simulation (DES) has been used to model human performance in a variety of environments dealing mostly with modeling of task timing, operator workload, and staffing issues. The structure of DES allows for the modeling of stochastic events in a relatively straightforward manner. This paper examines use of DES as part of human reliability analysis (HRA) and probabilistic risk assessment (PRA). An example of integrating an HRA/PRA with a DES is given for a nuclear power plant scenario. Sensitivity analyses are performed to show the effects of varying the type of alarm system used in the scenario and the use of procedures.

Zhuravlyov, G.E. (1998) “Ergonomic Provisions of the Shelter's Safety at the Chernobyl Nuclear Power Plant.” *Proceeding of the Human Factors and Ergonomics Society 42nd Annual Meeting*.

[Evaluation, Safety]

Notes that working conditions at the Chernobyl Shelter are extraordinary, insofar as not having prescribed procedures and or ergonomic assistance. This paper describes ergonomic problems that may arise at the shelter, with a description of several planned activities. The author acknowledges help from Stu Parsons.

Zohar, D. (2002). “Modifying supervisory practices to improve sub-unit safety: A leadership-based intervention model.” *Journal of Applied Psychology*, 87, 1, 156–163.

[Safety]

Describes the approach used by Zohar in industrial safety programs. Involves reliance on supervisors (e.g., foremen) to provide feedback and reinforcement for positive safety-related behavior.

Zufrin, A. & Juszkiewicz, K.T. “A Method of Estimating Operator's Working, Performing Efficiency.”

[Performance, Evaluation]

This paper discusses the authors’ development of devices and methods able to give current estimates of the body state without interruption of operator's activities/duties. The paper concentrates on the Measurement of Adaptation Processes method and its use for detection of changes in operator performance, state of fatigue, and/or health status.

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