Edited by

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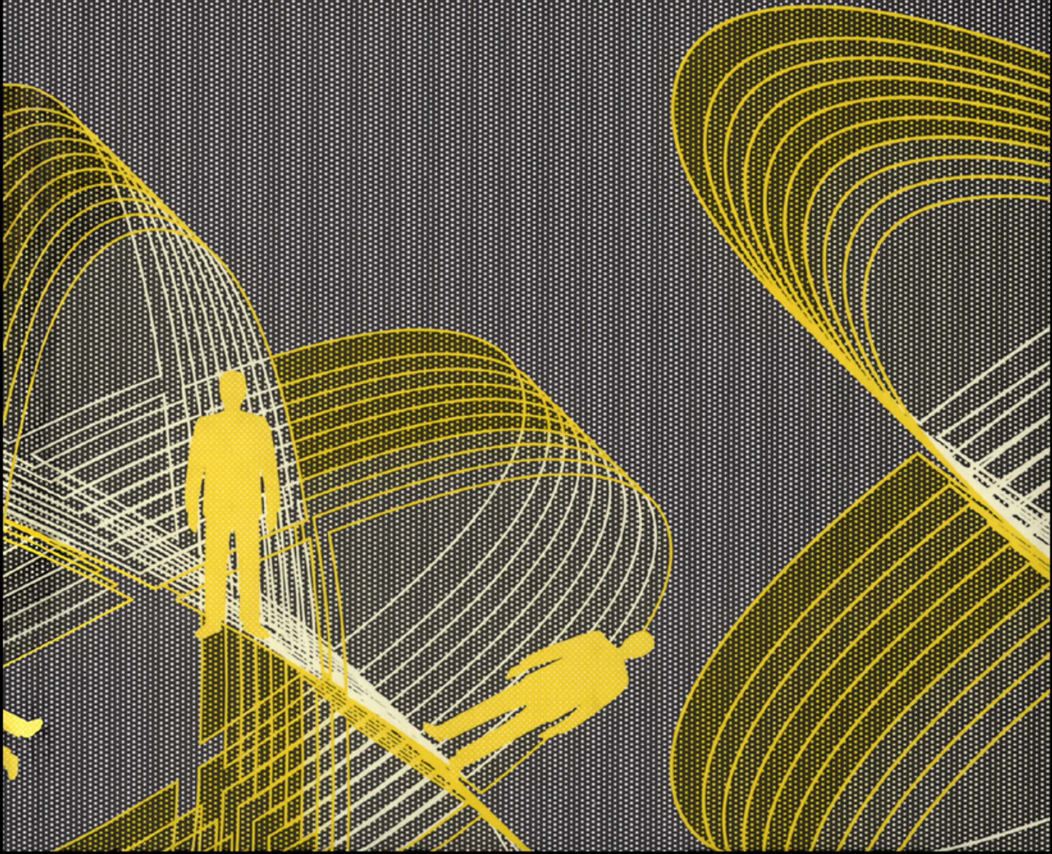
Safety Culture in Nuclear Power Operations



Also available as a printed book

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Safety Culture in Nuclear Power Operations

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TAYLOR & FRANCIS
Founded 1798

London and New York

First published 2001 by Taylor & Francis
11 New Fetter Lane, London EC4P 4EE

Simultaneously published in the USA and Canada
by Taylor & Francis Inc
29 West 35th Street, New York, NY 10001

Taylor & Francis is an imprint of the Taylor & Francis Group

This edition published in the Taylor & Francis e-Library, 2005.

"To purchase your own copy of this or any of Taylor & Francis or Routledge's collection of thousands of eBooks please go to www.eBookstore.tandf.co.uk."

Publisher's Note:

This book has been prepared from camera-ready copy provided by the editors

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Cataloging-in-Publication Data
Safety culture in nuclear power operations/edited by Bernhard Wilpert, Naosuke Itoigawa.
p. cm.
ISBN 0-415-24649-0 (alk. paper)
1. Nuclear power plants—Safety measures. 2. Industrial safety—Management. 3. Nuclear industry—Employees—Attitudes. 4. Organizational behaviour. I.Wilpert, Bernhard, 1936–II. Itoigawa, Naosuke, 1935–
TK9152.14.S34 2001
363.11'962148'35–dc21
2001027747

ISBN 0-203-30215-X Master e-book ISBN

ISBN 0-203-34628-9 (Adobe eReader Format)
ISBN 0-415-24649-0 (Print Edition)

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Preface

This volume is the second publication of a long-standing cooperation between the Institute of Social Research within the Institute of Nuclear Safety System, Inc. (INSS/ISR) and the Berlin University of Technology, Forschungsstelle Systemsicherheit (FSS—Research Center Systems Safety) within the Institute of Psychology. In 1993, INSS/ISR and FSS decided to jointly organize a series of international conferences on human factors research in nuclear power operations (ICNPO) with the aim “to initiate and facilitate contacts and interaction among the dispersed ongoing social science and human factor research in nuclear power operations of various countries in order to improve further safety and reliability of nuclear power operations” (mimeographed Conference Report of ICNPO I, Berlin, October 31-November 2, 1994). Whereas ICNPO I served as a first stocktaking of ongoing research among a select group of some 40 internationally reputed scholars, ICNPO II (Berlin, November 28–30, 1996), took a more focused approach and was published in 1999 by Taylor & Francis: J.Misumi, B.Wilpert, and R.Miller (Eds.), *Nuclear Safety: A Human Factors Perspective*.

The present volume is the result of ICNPO III, which took place on the premises of the INSS/ISR in Mihama, Japan, September 8–10, 1999. It addresses the various aspects of a new emergent concept in its relevance to the safety and reliability of nuclear installations: safety culture. Because of their overall strong safety record, nuclear operations may be characterized by features of low risk. However, their intrinsic hazards remain inseparable from the nuclear energy production process. Whereas safety research has in the past mainly focused on the quality, reliability, and availability of technical components, the significant role of human contributions to safety has become ever more evident. This fact gives special salience to the concept of safety culture as an integral notion that encompasses and requires the conscientious cooperation of all actors contributing to nuclear safety: governments, regulators, utility management, staff in nuclear power plants, manufacturers, consultants, and research institutions. Thus, it is hoped that the results of ICNPO III will be beneficial to the promotion of scientific efforts as well as the improvement of safety practice in the nuclear industry.

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Acknowledgements

We gratefully acknowledge the professional copy editorial work performed by Ginger A.Diekmann, and Hans Maimer's significant contribution to improve the figures and tables in this volume. Furthermore, the timely publication of this book would never have been possible without the efficient interface between authors and editors provided by Ulrike Wiedensohler, who also, with great competence, produced the final lay-out in strenuous efforts far beyond the call of duty. Finally, the financial support by the Institute of Nuclear Safety System/Institute of Social Research and of the Berlin University of Technology is appreciated.

The editors
Mihama/Berlin
February 2001

Introduction

BERNHARD WILPERT AND NAOSUKE ITOIGAWA

INTRODUCING A WIDER SCOPE—SAFETY CULTURE IN THE NUCLEAR INDUSTRY

The field of safety science, like any viable scientific domain, has been evolving over time. Reason (1993) has likened its development to three overlapping phases of safety concerns. First was the technical phase. An example can be found in early aviation: In response to frequently occurring accidents, airplane builders continuously optimized the design and material of technical components, thus improving aviation safety. Second came the human error phase, when it became evident that erroneous human action often produced accidents in spite of technically solid machines. The selection of capable operators and training for their competencies was the preferred choice of combating human threats to safety. Third was the socio-technical phase: During the 1980s it was recognized that the complex and often poorly understood interaction of social (human) and technical features had to be taken as the roots of large-scale system failures (Reason, 1993, referred to Bhopal, Chernobyl, Zeebrugge, King's Cross, Piper Alpha, and Clapham Junction as examples). Strategies to improve safety therefore had to address the joint optimization of the social and technical subsystems. The three foci of safety concerns—technology, individuals, and socio-technical features—all are confined in their main unit of analysis to individual organizations. However, as any thorough analysis of all major industrial catastrophes shows (Tokai-mura being a case in point), we have to take into account interorganizational dysfunctions as well. As a consequence, a fourth phase may be seen to emerge in recent years: the interorganizational phase (Wilpert & Fahlbruch, 1998), in which dysfunctional relationships among different organizations must be corrected in order to ensure sustained system safety. The need to add such a fourth phase is elegantly demonstrated in Rasmussen's contribution to this volume.

In view of the historical stages in the development of safety thinking, it should not come as a surprise that the concept of safety culture relatively recently entered the scene and international discourse within the nuclear industry. The term, brought up in the aftermath of the Chernobyl catastrophe (International Nuclear Safety Advisory Group, 1991), is still quite novel and in dire need of further clarification (see the contribution by Wilpert in this volume). However, the connotation of the term "culture" itself conveys the image of thorough and comprehensive pervasiveness. The association of it with the overriding concern of nuclear safety signals a programmatic penchant. Indeed, as all of the early publications on safety culture have shown, we are dealing with a concept that by necessity must encompass all relevant actors in their nuclear safety-oriented interorganizational relations: governments and regulatory agents, utilities and plant management, research institutions and manufacturers, consultant bodies, and nuclear power plant staff. Safety culture is defined and must be shared by all. Furthermore, the concept also covers all the central concerns of the four phases of thinking about safety: technology, individuals, the interactions of the social and technical subsystems, and the interorganizational relationships in their impacts on systems safety.

Safety culture is a complex and difficult term. Its various facets need to be unfolded on several levels. This volume attempts to accomplish this task by ordering the different contributions in four parts. The four chapters of Part One address the most fundamental issues in discussing the concept of safety culture itself and in illustrating the intricate and complex impacts of national setting or culture and of fundamental human endowment on what the term safety culture purports to achieve: improved nuclear safety. The three chapters of Part Two focus on economic and societal issues in their relationship to nuclear safety. Various response options of general safety management and organizational structuring in nuclear power plants are discussed in the seven chapters of Part Three. The concluding five chapters of Part Four deal with “people” issues, that is, with intervention possibilities likely to improve safety culture in operating individuals and groups involved with operations. Thus, we hope to unravel this complex notion of safety culture, from its fundamental basis, to the intermittent layers of social and societal aspects as well as its management and organizational features, all the way to the safety-oriented behavior of nuclear personnel.

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PART ONE

Conceptual bases of safety culture

Introduction

The contributions in Part One deal with fundamental issues of safety culture. They illustrate the multiple perspectives that must be applied if the desired goal of promoting a better understanding of this important and relatively new concept in safety science is to be achieved.

In the first chapter Wilpert offers a state-of-the-art review of organizational science's understanding of the cultural anthropological origins of the term "culture"; this particular understanding is seen as having entered safety-science theorizing by way of the notion of organizational culture. Safety culture, as a distinct and holistic concept, first entered scientific discourse in the aftermath of the Chernobyl catastrophe and is now adopted and adapted by virtually all high-hazard industries. The chapter concludes by outlining open issues for further theoretical clarification and the ensuing implications for methodological approaches and safety practice.

The socio-economic embeddedness of safety in all large-scale and complex high-hazard systems is the topic of Rasmussen's chapter. He outlines the requisite multilevel consideration in his attempt to analyze the efforts of high-hazard organizations to cope with the emergent challenges of their rapidly changing societal environment: technological change, changing regulatory requirements, increasing competition, and changing public opinion toward nuclear energy production. Rather than analyzing safety in the traditional mode of single-level decomposition of relevant factors, he advocates a multilevel functional analysis approach couched as a systems control task.

The cultural embeddedness of safety is treated by Moray in chapter 3 in his analysis of basic ergonomics such as population stereotypes, culturally or nationally preferred patterns of hierarchical work arrangements and of human resource management, automation philosophy, and communication patterns. Furthermore, he even interprets specific culturally determined personality types and basic orientations as possibly having significant implications for safety practices.

Human reliability issues in terms of basic human endowment form the topic of chapter 4 by Kirwan and Rea. Basing their study on a review of extant Human Reliability Analysis problems in U.K. nuclear power and reprocessing industries, the authors prioritize these problems and identify issues of recovery in low-probability events on the one hand and cognitive errors and errors of commission on the other as the two areas that deserve further work.

CHAPTER ONE
The Relevance of Safety Culture for Nuclear Power Operations

BERNHARD WILPERT

Resulting from the shock of the Chernobyl catastrophe, the term safety culture has rapidly gained currency in all high-hazard industries. This chapter first analyzes the roots of this new concept, tracing them back to cultural anthropology's two main understandings of culture as either "patterns of behavior" or "pattern for behavior." In line with modern organizational science's theorizing on organizational culture, the concept of safety culture is understood to comprise at least three analytical levels: (a) the deep layer of often unconscious basic assumptions and orientations, (b) shared values and norms, and (c) the directly observable artifacts and behavior patterns of organization members. The chapter then explores the practical relevance of safety culture in terms of its use as an educational vehicle, its limits and possibilities of change, and its contributions to the safety and reliability of nuclear installations. The chapter concludes with a reflection on open questions about theoretical development, methodology, and practice.

Civil nuclear power operations have so far demonstrated a remarkable level of safety. Despite the near disaster of Three Mile Island and the Chernobyl catastrophe, we may rightly categorize civil nuclear installations as belonging to the class of high-hazard, low-risk organizations, or High Reliability Organizations. This high level of safety can only be understood as the result of the nuclear industry's high safety standards from the very beginning of its development. These standards expressed themselves in a very conscientious design, high-quality manufacturing, effective regulation, and competent rule-bound operations. Further, an important ingredient of strong safety performance may have been the trustful, safety-oriented cooperation of all relevant actors: manufacturers, utilities, regulators, consultants, and research institutions. Thus, the nuclear industry has in many ways set standards for safe operations in other hazard industries as well.

Why, then, this sudden concern and excited preoccupation with a novel concept: "safety culture"? Will the concept amount to a surplus value of safety? Will it enhance further the art of safe operations? After all, the nuclear industry has all along been keenly aware of the absolute necessity of the human contribution to safe nuclear operations. The commitment to optimize the human dimension has therefore always been an important concern of the industry, even when the term safety culture did not yet exist. In the light of this track record of almost 50 years of civil nuclear power generation, the result of one of the first systematic international comparative studies of nuclear power plants does not come as a surprise: Worldwide the nuclear industry now subscribes to principles of safety culture, and this espoused commitment may today be considered a characteristic mark of the industry (Rochlin & Meier, 1994).

Culture seems to have become an omnibus term. Everyone uses it in a great variety of contexts. Some examples are corporate culture, investment culture, dialogue culture, leisure culture, and burial culture. Whence this ubiquity of the term culture? Little is known about the reasons for this expansive use of the term. One reason may be that culture is a broad term, and everyone may associate something with it; unfortunately, probably everyone associates it with something different. Another reason may be that many industrialized countries presently are undergoing dramatic changes of their economies and their societal values. Research from organizational science has shown that at times of significant social turbulence people tend to seek comfort by returning to historically proven values (Emery & Trist, 1965). And the notion of culture seems to convey connotations of wholeness, cohesion, commitment, and effectiveness (Dülfer, 1988; Meek, 1988). Furthermore, international comparisons of production efficiency, particularly comparisons of Western and Japanese automobile production, have suggested that culture may be an important determinant of some aspects of Japan's superior performance (Womak, Jones, & Roos, 1990). Thus, to link up with the concept of culture may appear to be a panacea for many of the problems facing society today. Training institutions and consulting bodies have seized that opportunity and made the promotion of corporate culture a self-propelling exercise. However, the ubiquitous use of the term sets barriers to its clarification (Büttner, Fahlbruch, & Wilpert, 1999). This observation is not to chide the everyday use of the term, for social science has its particular problems with the term as well. Already some 50 years ago, two of the most prominent anthropologists of their time noted roughly 170 different scientific uses of the notion of culture (Kroeber & Kluckhohn, 1952).

In short, it is timely to make yet another attempt at clarification of "culture" and, in the present context, "safety culture." I attempt this task in three steps. The first step consists of unfolding the origins and principal meanings of culture and safety culture. In the second step, I aim to highlight the practical relevance of the term safety culture for nuclear power operations. And in the concluding step, I point to some important open issues that need to be resolved.

CULTURE AND SAFETY CULTURE: ORIGINS AND MEANINGS

The term culture has its main roots in Anglo-Saxon social and cultural anthropology. Irrespective of the many connotations of the concept mentioned before, most of them can be grouped into two dominant camps. Considerable conflict about what should be the correct understanding of culture still exists among these camps. The first camp prefers to understand culture as “patterns of behavior,” the second as “pattern for behavior” (Keesing, 1974). The first camp means by culture all directly observable behavior and all manifest cultural achievements of the members of a collective, including the artifacts it creates (architecture, procedures, social structures, and institutions). We might call this camp the *concretist camp* because it focuses on patterns of behavior and maintains a descriptive focus on directly observable phenomena. The second camp understands the term culture as comprising mainly the socially transmitted psychic preconditions for the activities of members of a collective. These preconditions are the internal psychic structures, including the socially shared knowledge and fundamental convictions which serve as basis for the members of a community to order its perceptions and experiences, to make decisions and to act. They are not accessible to direct observation (Büttner et al., 1999). Culture is understood as the collective programming of minds (Hofstede, 1980) that constitutes a system of meaning for its members. This camp might be called the *mentalistic-cognitive camp,* given its understanding of culture as a pattern for behavior.

This distinction does not only have theoretical significance. It also has, as I show later, an eminently practical one. If management wants to influence culture it would have to change social structures and behavioral patterns. A mentalistic-cognitive perspective would imply the change of fundamental psychic preconditions.

It so happens that in the early 1980s organizational science appropriated the term culture in introducing the concept of “organizational culture.” Organizational culture has been a booming research paradigm ever since. Among the many theoretical approaches to conceptualizing organizational culture (cf. Allaire & Fisirotu, 1984), one has emerged as a dominant model because it achieves something of an integration of both camps: the approach by the American social and organizational psychologist Schein (1985). For Schein (see Figure 1.1), the essence of organizational culture consists in the unquestioned and often unquestionable preconscious deeper layers of basic orientations and assumptions that work unconsciously and define the way and how an organization views itself and its environment (Schein, 1985, p.

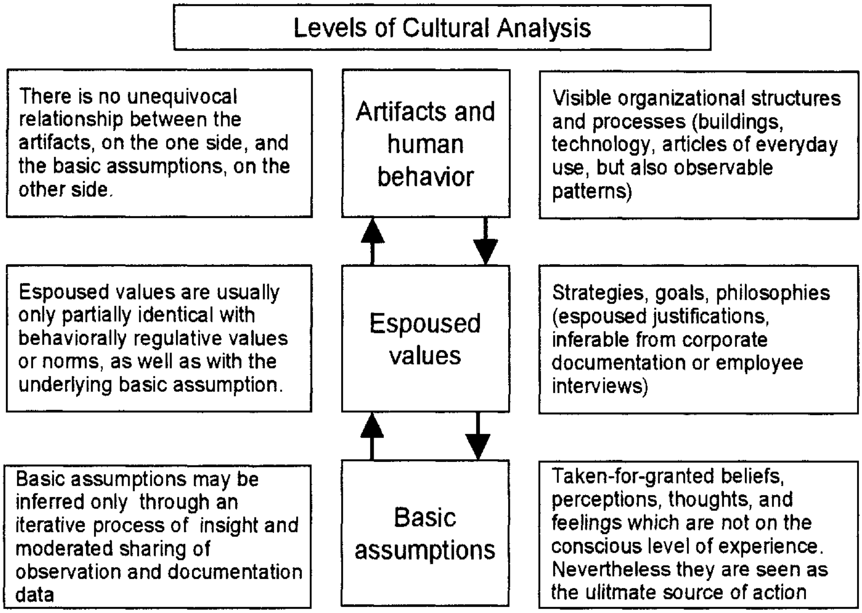

Figure 1.1 Levels of cultural analysis (adapted from Schein, 1985).

6). Thus, organizational culture provides meaning to its members. The next layer represents the shared values and norms of the organization, which often are more easily accessible by the consciousness, but which usually have to be conjectured from the actual behavior of members. And finally, in the (so to speak) uppermost layer one finds directly observable the actual behavior patterns of an organization's members, its technology, and artifacts. Schein thus developed his three-layer model of organizational culture. The three layers comprise both the concretist and the mentalistic-cognitive dimensions of received theories of culture. His model represents a very comprehensive, holistic conceptualization of organizational culture, which I use to orient my own analysis (see Figure 1.1).

Because the basic defining dimensions of an organizational culture are not directly observable, valid indicators of their manifestations are needed. This measurement problem attends any analysis of culture. Today it is assumed that a given organizational culture manifests itself in the organization's formal structures and processes, in the official and unofficial actions of its members, and in its culture supporting symbolic systems and concrete products (Sackmann, 1983).

The preconscious dimensions that define organizational culture and the unofficial actions of organization members alert one to a very important issue: Organizational culture cannot be changed at management's whims.

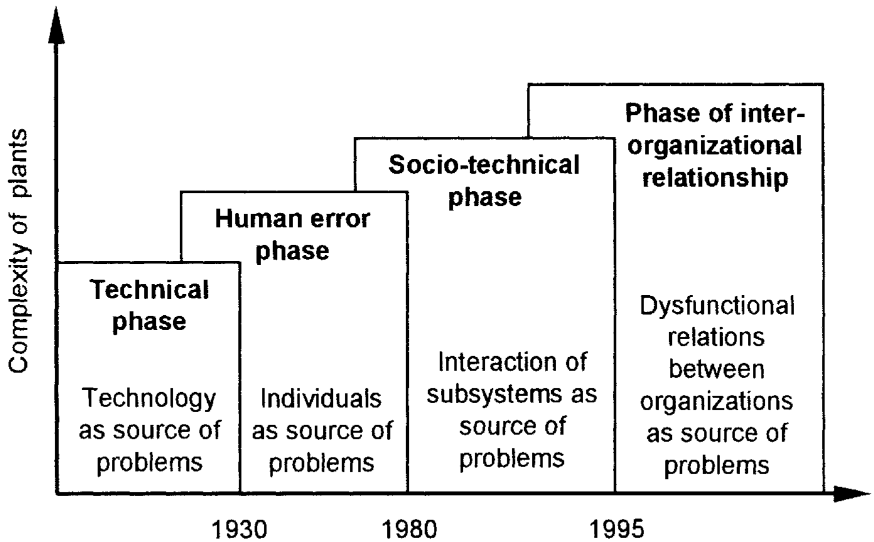

Figure 1.2 The phases of safety thinking.

Organizational culture is the result of a long and often laborious process of negotiation and implementation among all actors by means of which they define and construct their system of meanings. At the same time, this process means that contradictions and conflicts may very well exist between different membership groups.

Now, what about safety culture?

Before addressing this question a short excursion into the historical phases of safety science is in order. The notion of safety culture emerged for the first time when safety science was in its third or fourth historical phase. According to Reason (1993), the first phase of safety concerns may be called the technical phase (see Figure 1.2). In this phase, accident investigations focused on technical factors (protective devices and dangerous parts of the production process). This phase still may be dominant in the thinking of many engineers who try to take “unreliable humans” out of technical systems by replacing them with “reliable automation.” In any case, in this phase accident prevention was primarily sought through the optimization of technical components.

The second phase of safety began when it became evident that human ingenuity was always able to surpass technical safeguards by way of committing unforeseen and erroneous actions. This phase, the human error phase, therefore concentrated on avoiding operator errors. Its focus was on making investments into humans through optimizing the competence of operators by way of appropriate selection and training.

In the third phase, the so-called socio-technical phase, it was recognized that usually it was the complex and little-understood interaction of technical as well as individual, social, managerial, and organizational factors of the total system that created incidents and accidents (Reason, 1994). During this phase the socio-technical systems approach, developed already in the 1940s, came to full blossom.

This third phase overlaps with a fourth one, which colleagues and I labeled the interorganizational phase of safety science (Wilpert, Fahlbruch, Miller, Baggen, & Gans, 1999), in which incidents came to be analyzed and understood by including extra-organizational actors into the analysis: site personnel, utilities, regulators, contracting firms, consultants, and the interrelationships between these actors.

With reference to work accidents, there was also a precursory phase after World War I, when the British Industrial Fatigue Research Board (Greenwood & Woods, 1919) and, following its lead, German safety scientists developed the so-called theory of accident proneness. In this early phase it was assumed, and subsequently contentiously debated, that certain individuals tend more than others to be involved in human error and workplace accidents. However, in the context of this chapter I am in the first place concerned with complex system breakdowns and not with workplace accidents.

Back then to safety culture. With its holistic claims, the notion of safety culture is very much akin to the Socio-Technical Systems Approach (STSA) and Schein's conceptualization of organizational culture. However, its history is of more recent origin: Namely, it resulted from the shock of the Chernobyl catastrophe, when the International Nuclear Safety Advisory Group (INSAG) of the International Atomic Energy Agency tried to analyze and comprehend the Chernobyl events. The thorough analysis revealed that much more complex systemic dynamics than usually assumed had played a crucial role in bringing about the catastrophe. As brilliantly described by Read (1993), some explanatory factors of these dynamics reached back even into the history of the development of the Ukrainian civil nuclear energy program. Ever since 1986 the notion of safety culture has had an astounding international career in the nuclear industry and is already spreading into other industries. The concept clearly has the notions of culture and organizational culture as parents. Like both of its ancestors it, too, has reached the status of an omnibus category: Everybody has some apparent understanding of it, but, alas, possibly everybody a different one.

After several meetings INSAG agreed on the following definition in a small brochure (International Nuclear Safety Advisory Group [INSAG], 1991): "Safety culture is 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."

The definition refers to characteristics and attitudes of organizations and individuals. These factors are certainly important, but the definition remains too confined to the mental-cognitive area of attitudes. And it is known from a great deal of research evidence that attitudes and action do not always correlate highly. Already in 1991, therefore, I criticized the INSAG definition on the grounds that it leaves out what is of fundamental importance: safety-related behavior (Wilpert, 1991). The "working definition" of the British Advisory Committee on the Safety of Nuclear Installations (ACSNI, 1993) seems more precise and comprises factors that refer to the deeper defining dimensions of organizational culture as described by Schein: "The safety culture of an organization is the product of individual and group values, attitudes, perceptions, competencies, and *patterns of behavior* [italics added] that determine the commitment to, and the style and proficiency of, an organization's health and safety management" (ACSNI, 1993, p. 23).

Based on this working definition, safety culture may be understood, for the purposes of this chapter, as that aspect of an organizational culture through which all relevant actors treat risk and safety in nuclear installations. One could, however, also take another tack and claim that safety culture is the organizational culture of high-hazard organizations.

Irrespective of the critique of the INSAG definition, the INSAG text covers a set of factors which I deem very important. Of critical significance is the commitment to three levels: the level of individuals, the level of management, and the policy level. Furthermore, the text explicitly refers to the three most important groups that influence an effective safety culture: (a) government; (b) utilities and power plants; and (c) research, consulting, and manufacturing organizations. In this text one once again finds the above-mentioned understanding of a comprehensive safety system as it corresponds to the STSA (Wilpert & Miller, 1999). In its "Memorandum on Safety Culture in Nuclear Technology" (Reaktorsicherheits-Kommission [RSK], 1997), the German Reactor Safety Commission has taken a similarly comprehensive approach, describing safety culture as the result of contributions of all three groups mentioned by INSAG. It must be seen as a necessary condition that only with the optimal cooperation of all relevant actors can one expect an effective safety culture of the total safety system. "Safety is achieved only when everybody is dedicated to the common goal" (INSAG, 1991, art. 3). Thus, Fahlbruch and Wilpert (1999) have described system safety as "a quality of a system that allows the system to function without major breakdowns, under predetermined conditions with an acceptable minimum of accidental loss and unintended harm to the organization and its environment" (p. 58).

The Practical Relevance of the Concept of Safety Culture

Although a good deal has been thought and said about safety culture since Chernobyl, the field is still in a state of infancy. Nevertheless, I shall discuss some aspects that have convinced me of the practical relevance of safety culture for nuclear power operations. This attempt will be carried out under three headings: (a) safety culture as an educational vehicle, (b) the changeableness of safety culture, and (c) quality and availability.

SAFETY CULTURE AS AN EDUCATIONAL VEHICLE

As mentioned earlier, the nuclear industry has always played an important role in safety matters, setting the pace for other industries as well. A case in point is the remarkable progress of feed-forward safety control by treating safety and availability probabilistically. This approach has been a stronghold of engineering science. An impressive portfolio of proven methods and approaches has been developed in this area. More recently, there have been increased efforts to treat human availability with the same probabilistic logic. This task proves to be very difficult, if not impossible, because of the inappropriateness of probabilistic reasoning for the analysis of human error. Rouse and Rouse (1983) suggested that for human behavior, causal models rather than probabilistic ones need to be employed. But this issue needs to be discussed in a different place and time.

In the systematic analysis of major accidents in the nuclear field, such as Three Mile Island and Chernobyl, but also of accidents in other industries (Challenger, Bhopal, Seveso, Estonia, and Exxon Valdez are some of the relevant catchwords here), all the *ex post* investigations have convincingly demonstrated that it is insufficient to describe the breakdowns of large and complex systems exclusively in terms of technical component failures. Similarly, it is inappropriate to explain them solely through operator error. In fact, the preconditions of such events (and even those of minor incidents and near misses, not only of catastrophes!) are typically the outcome of highly complex interactions of individual, social, organizational, managerial, and design or construction factors. Such interactions of factors, which often are spatiotemporally very distant from the actual event, cry out for systemic causal understanding (Reason, 1994).

This is exactly where safety culture promises to introduce a change toward a more appropriate orientation and thinking. The notion of safety culture directs one's thinking toward sociocultural factors and a more holistic, systemic awareness. It introduces a paradigmatic volte-face from received engineering perspectives toward the complex and continuous interactions of man, technology, and organization. After all, safety is not something which, once it is achieved, can be taken for granted in the future. Rather, it is the result of a permanently ongoing process of safety-oriented action of all system members. This circumstance is, in a certain way, an ironic twist. I just lamented the vagueness of the term safety culture, but in this respect this very vagueness turns out to be an asset: The vague meaning of safety culture somehow offers itself as a projective notion into which people can project their own understanding. This situation leads to easier acceptance of the notion. Of course, it should not remain vague. Nevertheless, in its present state of ambiguity, safety culture, due to ist multiple connotations induces people also to open up to a new perspective. This opportunity is where I see the first significant aspect of practical relevance of the notion.

CHANGEABLENESS OF SAFETY CULTURE

For some people culture has a thoroughly positive meaning, connoting high cultural achievements in literature and the fine arts. However, this association does not hold if the term culture is considered in the context of its roots in anthropology. Here the notion of culture is value-free. The same case can be made for the term safety culture. It does not represent an exclusively positive semantic space. Rather, the term represents a continuum that may stretch from a positive pole to a negative one. There are good and bad safety cultures. If one wishes to implement good safety culture in plants, one must first know what counts as good, and, second, one must know how to introduce it. Again, in these very practical matters the nuclear power industry finds itself still very much in the beginning. However, there are some useful approaches that can be mentioned.

The INSAG model (INSAG, 1991) favors a top-down approach to the introduction and implementation of safety culture. It assumes that plant personnel reacts in a safety-oriented fashion to nationally valid safety rules, management safety policies, and the respective managerially arranged working conditions (part 3.3 of the INSAG document, 1991). This top—down model may very well be criticized because of its simplicity. The model has the structure of the stimulus-response paradigm of reflexology, which is well known in physiological psychology. The model is too simple for the complexities encountered in large-scale organizational development. There can be no doubt that management carries a primary responsibility for the introduction and sustained implementation of safety culture. Yet I have already pointed out that safety culture can only develop and exist on the basis of the interaction of all relevant actors in their continuous process of jointly constructing a safe reality in their plants. If this is so, then the stimulus—response model is inadequate. What is called for is the conscientious and active involvement and participation of all levels.

The Swiss Commission for the Safety of Nuclear Plants has recently brought out a very impressive document (Eidgenössische Kommission für die Sicherheit von Kernanlagen [KSA], 1997) on safety culture. With reference to the publication of INSAG (1991), the document identifies two main components of safety culture:

The first refers to the primary responsibility of management to formulate and systematically implement a safety-related corporate philosophy, to create an appropriate organizational structure, and to guarantee the requisite personnel and material means. The second component comprises the attitudes and behavior of the personnel at all hierarchical levels and the communication among them. (KSA, 1997, p. 4)

The document continues, again in line with INSAG (1991), to outline the need for basic action requirements of nuclear power plant personnel: a basic questioning orientation, careful and determined action, and communication. Furthermore, many concrete suggestions are made for the evaluation and enhancement of safety culture with reference to technology, division of work, organization, and incident analysis. It is worthwhile to note that there are already several measurement instruments and indicator lists that facilitate the description and evaluation of a given safety culture in a plant (Büttner et al., 1999; Fahlbruch & Wilpert, 1999).

A basic assumption of all these efforts for the evaluation and enhancement of safety culture in nuclear plants is that safety culture can be measured, introduced in plants, and optimized. In view of Schein's theory of organizational culture, this assumption is not self-evident. Schein explained that the crucial dimensions of an organization's culture are the preconscious basic orientations that are taken for granted and that are difficult to access and observe directly. They can be conjectured only via manifest indicators. There is still considerable research ground to be tilled here. Similarly, it may not be easy to influence such factors through organizational development interventions. Hence, for this area, organization developers need to think in terms of how many years it will take until the genuine effects of interventions become evident.

Quality and Availability

The true test of the practical relevance of safety culture lies in the proof that it contributes to the safety and availability of nuclear installations in a noticeable way. Definitive proof is not yet available. This circumstance is not too surprising, for a rather recent notion is being dealt with. However, one may derive from theoretical studies that positive effects can be expected. It is known, for example, that the high technical standards of the industry imply that only through optimizing the human dimension of safety factors can cost-efficient improvements be achieved. Further investments in technical elements will increase the safety level at best incrementally, and with tremendous cost to utilities. Further, if a commitment by plant personnel to adopt in all respects a basic questioning orientation and a systemic approach in their actions is successfully obtained, then one might expect that latent weaknesses lying dormant in the organization will be detected and corrected. Thus, critical conditions that may lead to incidents and loss of availability would be eliminated. Nevertheless, an ultimate proof of the practical relevance of safety culture as a useful industrial concept is still wanting. Quality, availability, competitiveness, and profitability might serve as criteria for such proof. I shall now offer a few reflections on the first two criteria, which are more in the domain of organizational psychology; the latter two belong to the field of business administration.

Quality

Referring to the quality of a process rather than a product, most authors who deal with safety culture see in it similarities to the objectives of quality assurance. Quality management has become a major preoccupation of many industries. The question to ask is, therefore, how safety culture may be reflected in quality assurance programs. I can refer to one study that offers some hints on the relationship of safety culture and quality. Gaunt (1989) conducted a study of 626 plants, where he used an auditing technique based on the International Safety Rating System (ISRS) and 34 organizational performance parameters. After an investigation period of two and a half years, he noted that safety consciousness in the plants using ISRS had improved and, in particular, that working methods had been optimized and absenteeism had declined. This study gives a first indication that safety culture has economic effects as well.

Availability

With regard to availability research, evidence is not only sparse but also apparently contradictory. Swanson (1982) claimed in a lapidary manner: “Safety is not equal to availability.” One might respond that at the time his article appeared, the concept of safety culture did not yet exist. Besides, a reactor scram may often be interpreted as an indicator of properly functioning safety systems indicating a safe plant. However, encouraging evidence comes from research on High Reliability Organizations. A research group based at the University of California at Berkeley is engaged in research on the safety of nuclear airplane carriers and nuclear power plants. The explicit goal of the research is to identify those factors that lead to the astounding reliability of these installations. The preliminary finding of the group is that highly reliable organizations are characterized by an intensive and heedful interaction of all personnel categories and a work environment that is always created by management in correspondence with risk demands (LaPorte, 1996). It is exactly these two components of safety culture that were mentioned by the Swiss Commission for the Safety of Nuclear Plants.

Although this finding is again not final proof of the practical relevance of safety culture, it is at least an encouraging sign.

OPEN QUESTIONS

By way of conclusion I would like to address a few extant problems in connection with safety culture that need to be resolved. These questions refer to theory, methodology, and practice.

Now that the notion of safety culture has been accepted worldwide, the most important immediate task at hand seems to me to be the need to further clarify and define the theoretical notion of safety culture. This task is in the first place one of scientific endeavor. But it must be carried out in continual interaction with practice. Given the present state of the art, this task must be carried out by clarifying, from a sound theoretical basis, the most important dimensions of the notion and by testing them in cooperation with practitioners. Particularly urgent in this respect seems to be the identification of the relationship between explicit safety regulations and of the implicit, unspoken behaviors guiding norms. Similarly important appears to be the unfolding of the preconscious dimensions of culture that make people act automatically without conscious reflection. An issue that is somewhat related to an attempt to unveil the preconscious dimensions of safety culture is the task of clarifying the relationship with and dependence of safety culture from its surrounding national culture. Judging from theoretical studies, one would expect that safety culture will be influenced by its national cultural context (Meshkati, 1999), and the first empirical studies have lent corroborative evidence for this hypothesis (Bourrier, 1999; Fujita, 1992; Rochlin & Meier, 1994).

In terms of methodological advances, what next seems necessary is the development of practicable and valid instruments to measure these dimensions. By "practicable instruments" I mean methods that allow scientists, but also auditors, plant personnel, regulators, and consultants, to ascertain and evaluate as precisely as possible the status of safety culture in a given plant. This need is particularly important in view of the fact that only on the basis of valid measurements of these dimensions will researchers be able to push further in proving the practical relevance of safety culture with reference to criteria such as quality, availability, competitiveness, and profitability.

A third task refers to the introduction, implementation, and sustained enhancement of safety culture in nuclear plants but also among all relevant actors of the nuclear safety system. Essential in this respect is the development of appropriate intervention approaches, which in part must address utilities and their plants alone, but which often must be geared toward interorganizational relations as well. The achievement of this goal cannot be done on command: It requires the trustful cooperation of all relevant actors.

CONCLUSION

The concept of safety culture was developed in the aftermath of the Chernobyl catastrophe. It signaled the international nuclear community's growing awareness that nuclear plant safety must be conceived in much more holistic terms than it had been articulated by the nuclear industry when that tragic event occurred in 1986. The concept calls for a total systems perspective of safety that comprises all relevant actors who contribute to nuclear safety. The notion of nuclear safety culture is thus a normative concept that does not limit its consideration of factors influencing safety to the confines of nuclear plants. It encompasses all constituent parts of a nation's nuclear safety system: the plant with its technology, staff, management, and organization; the utility; manufacturers; and regulators, all the way up to the relevant elements of the national cultural context.

Safety culture is still a young concept and in dire need of further development so that it can be fully integrated into safety management systems. In spite of its theoretical and methodological shortcomings, the concept has been widely accepted in a short time, and its use is quickly spreading to other high-hazard industries. In directing attention to wider horizons in safety thinking, safety culture presents itself as a unique medium and catalyst in the necessary development of an international consensus of what is required for nuclear safety. In this function it has already proven its practical relevance. The ongoing accumulation of concrete experiences in implementing and enhancing safety culture in nuclear plants as well as the complementary research evidence currently being compiled will undoubtedly prove that the concept should in future remain of overriding importance.

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CHAPTER TWO

Nuclear Power and Societal Problems in Risk Management

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Presently, nuclear power is in focus of the public safety concern and several governments are forced to reconsider its continued role in the national power policy. In this situation it is mandatory for the utilities and the industry to present credible risk management strategies. Development of systematic methods for industrial risk assessment has been advanced through decades in particular within this technological domain. However, the society surrounding the nuclear industry has changed in several respects, being increasingly dynamic and competitive with new trends in legislation and management such as deregulation and pressure toward cost-effectiveness. In this situation, it is necessary to reconsider the basis of risk management strategies and the underlying research. The presentation will give a review of the characteristics of the changing society and the implications for effective risk management. Based in this, some basic problems in the present models of accident causation are described with their influence on risk management strategies. Some critical research problems are identified and illustrated by examples of accidents within shipping, aviation, etc. and parallels drawn to the conditions of nuclear power.

Industrial organizations, including the nuclear industry, presently are facing a changing environment due to deregulation, an aggressive public opinion, and increasing commercial competition. In this situation, a reconsideration of the risk management strategies could be worthwhile.

Analyses of industrial accidents invariably conclude that some 80% of the cases are caused by human error and great effort is spent to improve safety by better training schemes, by safety campaigns motivating the work force to be safety conscious, and by improved work system design. However, low risk operation of modern, high hazard system normally depends on several lines of defenses against the effects of faults and errors. The analysis of recent major accidents has also shown that they are not caused by a stochastic coincidence of faults and human errors, but by a systemic erosion of the defenses. In this situation, it will be necessary to consider the distributed decision making and the involved information flow in the entire socio-technical system in which the hazardous production systems are embedded.

ACCIDENT CAUSATION

Injuries, contamination of environment, and loss of investment all depend on loss of control of a physical process capable of injuring people or damaging property. The propagation of an accidental course of events is shaped by the activity of people that either can trigger an accidental flow of events or divert a normal flow. Safety, then, depends on the control of work processes, so as to avoid accidental side effects causing harm to people, environment, or investment.

Many levels of politicians, managers, safety officers, and work planners are involved in the control of safety by means of laws, rules, and instructions that are verbal means for the ultimate control of some hazardous, physical process. They seek to motivate workers and operators, to educate them, to guide them, or to constrain their behavior by rules, so as to increase the safety of their performance, see Figure 2.1.

Such migration toward accident is caused by the side effects of decisions made by different actors working in different organizations, at different levels of society, and during activities at different points in time. These decision-makers are deeply immersed in their individual normal work context, striving to meet objectives under pressure from local performance criteria. Their daily activities are not functionally coupled, only an accident as observed after the fact connects their performance into a particular coupled pattern. By their various, independent decisions and acts, they shape a causal path through the landscape along which an accidental course of events sooner or later may be released. Very likely initiated by yet another quite normal variation in somebody's work performance—which probably then will be judged the 'root cause' after the accident.

To be able to improve the safety level, we should not focus on removal of such 'root causes' of past incidents in terms of human error. Instead we have to understand the mechanisms generating the actual behavior of decision-makers at all levels. We have to analyze the communication that takes place among them during normal work, and to identify the information exchange necessary to identify the boundaries of safe performance. From here, we have to identify aspects that are sensitive to improvement and, therefore, the targets of guidelines for future risk management.

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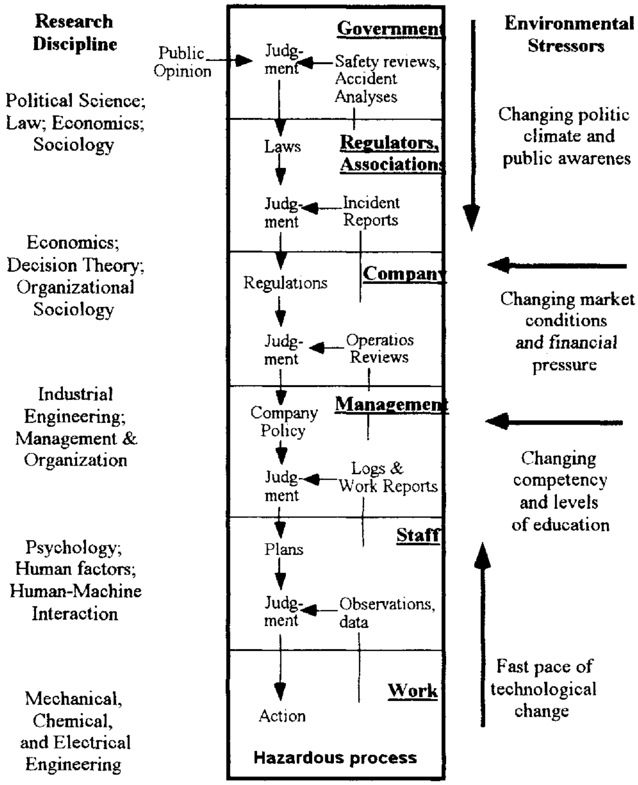

Figure 2.1. Many nested levels of decision making are involved in risk management and regulatory rule making to control hazardous processes. This social organization is subject to severe environmental pressure in a dynamic, competitive society. Low risk operation depends on proper co-ordination of decision making at all levels. However, each of the levels are often studied separately within different academic disciplines.

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THE CHANGING SOCIETY

Compared to the stable conditions of the past, the present dynamic society brings with it some dramatic changes of the conditions of industrial risk management.

Rapid Technological Change

A rapid pace of change of technology is found at the operative level of society within all domains, such as transport, shipping, manufacturing and process industry. Even if the nuclear power technology is in a rather stable phase, technological changes are found in many sectors, such as introduction of computer based control and safety systems and other auxiliary systems. Typically, this change is faster than the pace of change of management structures and in legislation. In consequence, a problem is found in the different time constants of change at the different levels of society. The analyses of past accidents indicate that the communication between system designers, constructors, and system operators should be carefully considered during a period of fast change. During stable periods, communication relies on a mutually shared competence and the need for more explicit functional explanation following a change in technology is often not considered adequately.

Changing Regulatory Policy

The socio-technical system is subject to changing government policies in several countries in terms of a change from prescriptive toward performance-based legislation and industrial deregulation.

This trend is found for several types of risks in the US. Since the regulatory process typically requires 6–10 years to develop adequate prescriptions, the fast technological pace of change has led to the introduction of the 'general duty clause' that has substantially enhanced the regulator's ability to protect workers during the latest decades (Baram, 1996). This clause states that each employer "shall furnish to each of his employees a place of employment that is free from recognized hazards that are causing or are likely to cause death or serious harm to his employees."

In this way, it is required that certain generic functions are carried out to avoid accidents, leaving the details as to how the functions should be carried out to the companies (or other regulated organizations). Such trends are clearly an implementation of the closed-loop, feedback design concept. In this way, detailed rule-making takes place at a level where the context is known, and this change clearly also changes the role of decision makers within the social control hierarchy, and it changes the need for information about the detailed work context at the upper levels. It will also change the need for interaction between regulatory decision-makers and substance matter experts (Rasmussen, 1997).

According to Baram, the new performance rules and reinforcement policies pose several problems for most companies. First is the big uncertainty of what it must do to carry out each function in an appropriate manner (since the rule requirements are broadly expressed). Uncertainty often translates into greater cost and difficulties for line management. The second problem is how to cope will the pressures from persons at risk who are stimulated by the disclosures. To cope with the first problem, many companies are developing their own detailed internal, prescriptive rules, so that there is now an even greater prescriptive rule culture within such companies. For the second problem, companies are using attorneys and public relations people to deal with the new pressures caused by transparency. The third problem involves uncertainties about the management system needed to prevent violations, and is being dealt with by following the efforts of standardization organizations (e.g., ISO and EMAS) to define good management systems. Companies also face a fourth problem of how to manage their rule compliance efforts under the stress of reorganizing (contracting outside for work previously done within the company, developing strategic alliances with other companies, etc.).

With generic regulation, safety should be controlled by active performance objectives and become just another criterion of a multi-criteria decision-making. As mentioned, it should be an integrated part of normal operational decision-making. In this way, the safety organization is merged with the line organization. Such modern attempts to delegate decisions and to manage by objectives call for an explicit formulation of value criteria and effective means for communication of values down through society and organizations. Interesting developments have been presented for this kind of distributed organization and formal strategies have been proposed for 'ethical accounting' to ensure that the impact of decisions on the objectives and values of all relevant stakeholders are adequately and formally considered (Bøgetoft and Puzan, 1991).

Aggressive Competition

Companies today live in an increasingly aggressive and competitive environment that very likely will focus the incentives of decision-makers on short-term financial criteria rather than long term criteria concerning welfare, safety, and environmental impact. This situation calls for an increased regulatory effort to influence the management incentives of hazardous industries—also during a period of deregulation.

Traditionally, studies at the upper levels of Figure 1 are based on analyses of samples of organizations or groups of people with no detailed consideration of the actual hazardous processes found at productive bottom level. Management theories tend to be independent of the substance matter context of a given organization (Barley, 1988). To be manager is regarded as a profession, independent of what you are managing; a hospital, a manufacturing company, or a bank. Therefore, the aim of commercial companies presently appears to change from being organizations serving a particular substance matter domain toward a narrow focus on financial operations (Engwall, 1986). What are the implications of this situation on the societal control of the safety of industrial installations?

Following a recent Scandinavian ferry accident (Scandinavian Star fire), a marine safety official noted on a TV interview that we might see a decrease in naval safety, since ships were increasingly operated by banks and investors rather than shipping professionals. Commercial conflicts between institutions and companies at the various levels have been identified from super tanker and roll on—roll off ferry accidents (see Shell, 1992, Estonia, 1995, Stenstrøm, 1995). Examples are:

- Shipping industry influences legislators: Depressed shipping market leads to changes in its structure. Underwriters and National Administrations are neutralized by competition.
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- Ship owners influence classification societies.
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- Owners and classifiers co-operate and do not inform legislators adequately.
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- Communication from classifiers to designers is inadequate.
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- Communication between designers, ship yards, and operators has been inadequate during a period of technological change.

Similar conflicts are found within the aviation domain, see Schiavo, 1997. For improved risk management strategies, an analysis of such commercial interference with risk communication is mandatory.

Public Pressure and Risk Communication

The public is becoming very conscious about industrial risk sources and pressure groups have an important political role. It is now required that risk management should be ‘pro-active’ rather than reactively responding to past accidents. The communication between hazardous industries and the general public needs to be improved. This communication has suffered from the different languages and representations used for common sense reasoning and within natural science and engineering.

Ambiguity of Causal Explanations

The basic difference between the relational representation dominating natural science and engineering and the causal representation used for causal explanations and natural language arguments leads to problems in the communication between technical system designers, operating organizations, and the general public.

A classical engineering analysis is based on mathematical equations relating physical, measurable variables representing relationships that are ‘practically isolated’ (Russell, 1913). This is possible when they are isolated by nature (e.g., being found in the planetary system) or because a system is designed so as to isolate the relationship of interest (e.g., in scientific experiment or in a machine supporting a physical process in a controlled way). This representation is particularly well suited for the analysis of the optimal conditions and theoretical limits of physical processes in a technical system that, by its very design, carefully separates physical processes from the complexity of the outside world. This isolation breaks down in case of accidents, and for accident analysis, a causal representation is applied.

A causal representation is expressed in terms of regular connections of events. Russell (1913) discusses the ambiguity of the terms used to define causality. The concept of an ‘event,’ for instance, is elusive. The more accurate the definition of an event, the less is the probability that it is ever repeated. Completeness removes regularity. Definition of occurrences as events in causal connection does not depend on categories which are defined by lists of objective attributes but on categories which are identified by typical examples, prototypes. A causal explanation depends on a decomposition and search for unusual conditions and events. The normal and usual conditions will be taken for granted, i.e., implicit in the intuitive frame of reference (Rasmussen, 1990). Therefore, in causal explanations, the level of decomposition needed to make it understood and accepted depends entirely on the intuitive background of the intended audience. If a causal statement is not being accepted, formal logical analysis and deduction will not help, it will be easy to give counter-examples that can not easily be falsified. Instead, further search and decomposition are necessary until a level is found where the prototypes and relations will match the intuition of the audience.

Causal Arguments and Public Acceptance

This dependence of the acceptance of causal explanations upon a shared intuition may very well be the reason that nuclear power opponents do not accept the arguments of nuclear power operators, rather than the lack of understanding of risk and probability that is often used as an explanation. In order to improve the public acceptance, it will be necessary to give up the defensive attitude and get into an open exchange with technically interested members of the public. To be evasive and protect information about faults, errors, and incidents is counter productive. The safety of technical systems protected by the defense-in-depth strategy is depends on several independent barriers. The number of such barriers is chosen to be high enough to reach an acceptable low probability of large-scale accidents, even when the *failures of the individual barriers are frequent enough to be controlled and verified empirically*. Reports on failure of individual barriers therefore are not indicators of lack of safety, but demonstrate an active monitoring effort.

Unfortunately, it is not straightforward to turn around the public opinion, but success stories are found. Knowles (1993) has described how this was done at the Union Carbide Belle plant by inviting the public to visit the plant and by opening a lecture facility in a nearby mall. This helped to define a shared context with the technical opinion leaders, ultimately serving to establish public acceptance.

Presently we are faced with considerable pressure toward decreased release of CO_2, with an increasing energy need of developing countries. Considering also the potential for development of safer, closed-cycle nuclear plants, efforts to improve the risk communication between the public and the nuclear industry appear to be mandatory.

RESEARCH NEEDS

The usual approach to modeling a work system within human sciences is to decompose it into elements that are modeled separately. This has some peculiar effects. The socio-technical system involved in risk management is, as shown in Figure 1, normally decomposed according to organizational levels which are studied separately within different disciplines, each having a ‘horizontal’ orientation of research across the technological hazard sources. To really improve risk management in the present dynamic society, we need careful studies of the ‘vertical’ interaction among the levels of the socio-technical systems with reference to the nature of the technological hazard they are assumed to control.

For this research, we need a change from studies based on structural decomposition of the socio-technical hazard control system toward studies based on a functional abstraction into relationships (see the distinction discussed above). This involves a shift from generalizing factor analyses across hazard sources and an empirically based 'safety culture' toward a control theoretic focus on the information flow structure in the entire system together with a proactive, analytically based risk management strategy matching the control requirements of the relevant hazard sources.

DECISION MAKERS, COMPETENCE, AND COMMUNICATION OF CHANGE

The conclusion of this discussion is that the communication within the risk management should be reconsidered in control theoretic terms with careful analysis of the degeneration of communication, that usually follows evolution of shared expertise.

Accident Analysis, Laws, Rules, and Instructions

Risk management is depending on communication among the organizational levels in Figure 1. Laws, regulations, and instructions are typically based on findings from past accidents and technical analyses and then communicated down through the levels. Laws and rules have typically been prescriptive and based on a causal model of activities in terms of sequences of events, decisions, acts, and error opportunities.

However, regulators and work planners are not able to foresee all the local contingencies of the work context. In particular, a rule or instruction is often designed separately for a particular task in isolation whereas, in the actual situation, several tasks are active in a time sharing mode which poses additional constraints on the procedure to use, which were not known by the designer or work planner. The problem is that all work situations leave many degrees of freedom to the actors for choice of means and time for action even when the objectives of work are fulfilled. To complete an instruction for a task in terms of a sequence of acts, these degrees of freedom must be resolved by assuming additional performance criteria that appear to be 'rational' to instructors but may not be so for the actors.

In consequence, rules, laws, and instructions practically speaking are never followed to the letter. Strikes by civil servants take the shape of "working-according-to-rules." Even for highly constrained task situations such as nuclear power operation, modification of instructions is repeatedly found (Fujita, 1991, Vicente et al., 1995) and operators' violations of rules appear to be quite rational, given the actual work load and timing constraints. One important consequence of this is that following an accident it will be easy to find someone involved in the dynamic flow of events that has violated a formal rule by following established practice. Consequently, accidents are typically judged to be caused by 'human error' on part of a person involved in the dynamic course of events, that is, a process operator, a train driver, or a pilot.

The conclusion is that 'human error' is not a reliable explanation of accidents. Instead of considering operators to be the weak, vulnerable part of technical systems, they should be considered flexible, the *competent cooperators of system designers*. They are in fact in the system to complete the design of the system during conditions that were not foreseen by the designers, and the use of prescriptive instructions should be reconsidered. This focuses attention on operator competence and professionalism.

Competence, Professionalism, and Instruction

In an instructive paper, Colas (1994), from EDF—Electricité de France—has discussed the need to formulate the characteristics of operator professionalism. He argues that to have professional operators, it is necessary to respect their professionalism and not to instruct them in matters in which they are the experts.

This aspect of instruction focus attention on the characteristics of communication among experts within an organization and its influence on safety.

Forms of Competence

A closer look at the information used by actors to control their activity is necessary to define professionalism and competence. It is useful to distinguish between cognitive and meta-cognitive competence.

The cognitive competence includes all forms of knowledge about the work space that is used to control actions, represented explicitly in terms of a model of the relational structure, or implicitly in terms of know-how, rules of action, or manual skills.

The *meta-cognitive competence* includes the 'style of work' adopted by actors, a kind of working culture depending on factors such as 'cognitive style' and 'management style.' When the primary goal of work and its cognitive requirements are satisfied, many degrees of freedom in work performance still exist which must be closed by situational and subjective performance criteria, such as risk of failure, work load, time spent, or social acceptance. An actor's priority ranking of such criteria depends on a kind of 'cognitive style.'

In his discussion of *professionalism,* Colas makes a similar distinction, quote (op. cit. p. 4):

> Fundamentally, professionalism aims to make actions more reliable by implementing appropriate work methods. These more thorough methods refer to intellectual activities (analysis, diagnostics, choice of appropriate responses, etc.) and to "culture" (perception and value accorded to safety and production) and, consequently, to the

> willingness to act in a certain way, which in turn flows from a state of mind, attitudes and behavior.

For the formulation of the principles for implementation of professionalism, it is therefore argued that two different aspects should be considered separately (Colas, 1994, p.6):

> Knowledge, learning or know-how in its technical dimensions and conditions for taking action in order to provide a technically viable response.
>
> The appropriate methods and attitudes which ensure that this technically satisfactory response corresponds fully to the quality and safety requirements imposed by our industry, which are adapted to the organization of our activities.

In the following paragraphs, these two aspects of competence are reviewed with reference to the SRK framework.

Competence at the Skill-based Level

During familiar circumstances, sensory-motor routines take care of the direct control of integrated patterns of movements. The flexibility of skilled performance depends on the ability to compose from a large repertoire of such movement patterns the sets suited for specific purposes. The individual patterns are activated and chained by perceived patterns that are acting as signs, and the person is not consciously choosing among alternatives.

Competence at this level thus is achieved by development of a repertoire of dynamic behavioral patterns that are synchronized effectively with the behavior of the workspace. Behavioral optimization is guided by criteria such as speed and smoothness, and how far this adaptation can be accepted is only indicated by the once-in-a-while experience gained when crossing the tolerance limits, i.e. by the experience of slips. At this level, therefore, expertise depends on a speed-accuracy *trade-off* and 'errors' have a function in maintaining a skill at its proper level.

Cognitive aspects of this competence include the repertoire of sensori-motor patterns with a scope and flexibility necessary for smooth and fast use of tools and equipment relevant to a particular profession and work place. They serve quick navigation in the work environment and identification of work items. This competence includes the ability to organize routine movement patterns into integrated patterns, synchronized with a wide variety of work situations.

Meta-cognitive aspects includes a sensitivity to detailed features of the environment thus enabling the detection of minor changes calling for modulation of the behavioral patterns. Furthermore, professionalism includes an intuitive sensibility that will interrupt subconscious, skilled performance, when resort to conscious choice or situation analysis is required.

Communication with the work environment at this level depend on perception of *time-space signals,* serving to up-date and synchronize behavior with the task space, perception of the 'body-language' of collaborators during shared tasks.

Competence at the Rule-based Level

Once in a while, direct chaining of motor patterns is not possible, because two or more familiar patterns apply to the immediate situation, in which case cognitive control is switched to the rule-based level.

An actor immersed in his work is typically well synchronized with his environment. He is familiar with the situation and only has few options for action at any given time. Consequently, an expert will only need to look for the information necessary to distinguish between these few options, and he will develop a repertoire of cue-action correlations, he needs not consult the complete set of defining attributes before acting in a familiar situation. Instead, guided by the path of least resistance, they will seek no more information than is necessary for discrimination among the perceived alternatives for action in the particular situation. Therefore, when situations change, e.g., due to disturbances or faults in the system to be controlled, reliance on the usual cues that are no longer valid may lead to error. Again, a *trade-off* takes place: Speed versus the risk of a latent change of context that may make the actor's know-how obsolete.

The *cognitive competence* at this level includes 'know-how,' that is a large repertoire of cue-action sets matching a wide variety of work situations and tasks. Furthermore, professional actors should have a high sensitivity to secondary situational features that indicate the presence of invalid cues and a need for a situation analysis at the knowledge-based level.

The *meta-cognitive aspects* at this level include a proper balance among the performance criteria, such as speed, workload, and risk of failure together with a high sensitivity for secondary cues that indicate changes in the familiar cue-action set. This involves a high degree of flexibility to avoid fixation on normal procedures—an important item for simulator training. This competence also includes social skills in teamwork and sensitivity to competence and information needs of colleagues.

Communication at this level serves to control a sequence of actions. When operating on a physical workspace, an actor will select convenient cues from the information available. When cooperating with other actors, this also takes place, but in addition, the information available will depend on the formulation of messages by the other actors.

During collaboration in a professional team, an actor will be very well aware of the options for action facing a colleague and he will be familiar with the competence of his colleagues. In that case, he will very likely only communicate the information, he finds adequate to resolve the choice among the assumed options of the colleague. Observations of the communication within professional work teams in transportation of hazardous goods have shown that very little information is actually exchanged, as long as work conditions are normal (Svedung et. al., 1999). Functional information is only discussed when it is realized that changes have taken place or that demands are unusual, This change is then followed by a shift to knowledge-based control of activities.

Competence at the Knowledge-based Level

When situations are met, for which know-how is inadequate, control moves to the knowledge-based level, based on deduction of rules by means of a mental model. Faced with an unusual situation, a hypothetical explanation is formed and tested conceptually before action is taken. The result of the ultimate action is a test of this hypothesis. The question then is when to stop thinking and start action? The answer depends on a *trade-off* between delays due to indecisiveness and the risk of a premature decision. This trade-off depends on many subtle situational factors that usually cannot be made explicit at a later point in time. In case of an unsuccessful result it is likely to be judged a decision error, even when the decision was quite rational, given the local circumstances.

The *cognitive competence* at this level is related to the extend and quality of the understanding of the relational, causal structure of the work system, that is, a correct mental model of system function, and to the knowledge about system goals, safety conditions and regulatory constraints on performance, etc.

Also important is the ability to perform mental experiments to generate rules for action toward a certain goal and to test hypothesis about the cause and effect of abnormal system behavior. Finally, knowledge about information sources, manuals, textbooks, diagrams and the ability to use them belongs to this level.

To the *meta-cognitive* aspects belong proper ranking of production versus safety criteria guiding trade-off during ambiguous situations, including sufficient 'cognitive awareness,' that is, the use of basic understanding to monitor system performance also during routine conditions and thus be sensitive to changes.

Communication. The cognitive competence is very much related to the ability to interpret the *content* of communications and observations with reference to the use of a functional, relational model of the work content.

The meta-cognitive aspects of competence required for cooperation relates to the *form* of communication, such as care when formulating messages, and not to use rudimentary short-hand messages during periods of change.

Important is also the extend to which feed-back to cooperators is maintained to verify performance. Short-hand messages in cooperative context are analogs to convenient cue-action relations in direct interaction. There is, however, one important difference. Formulation and reception of short-hand messages depend on the mutual perception of competence of both the sender and the receiver. Differences in their meta-cognitive competence, or in their mutual perception of the partner's level of competence, is likely to lead to misinterpretation, unless the feedback verification mentioned is active.

Findings from Accident Analysis

The influence on risk management of experts' adaptation to the normal features of their work conditions and their reliance on intuition about the competence of their colleagues is demonstrated by Hopkins' (1998) analysis of the decision making of the management of the Moura mine in Australia.

The mine company was under considerable pressure due to a contract to deliver coal to a new power plant from its fixed start-up date. This influenced the performance criteria of managers and a number of unsafe decision making routines evolved, leading to an explosion:

- A tendency to discount unwanted evidence: A culture of denial. It was generally believed that there was no significant risk and given the production pressure there was a strong tendency to dismiss any contrary evidence. This may reflect the fact that experts do not base actions on a situation analysis, but on convenient cues.
- A hierarchy of knowledge was instituted and knowledge based on personal experience was far the most influential, while information acquired by word of mouth was more influential than written information. This was not just a practice; it was a policy, spelled out in the mine's Quality Assurance system. The mining procedures had not been considered by the manager-in-charge, even he was responsible for the underground procedures. He considered them just to reflect what was already happening in the mine. This may reflect the condition that important messages may be lost when embedded in information that is already part of the receiver's normal, professional competence.

Several observations seem to be related to the adoption of rudimentary communication within a team of experts, and to the difficulties in actually shifting to the level of knowledge-based communication:

- Managers at the levels above did not pay much attention to the reports of their Deputies. It was generally expected that important information would have been communicated orally.

– When the decision was taken to seal the panel earlier than initially intended, none of this information was conveyed to miners or deputies. The manager assumed that everyone had been informed via the 'grapevine.'

Similar communication patterns are found in other organizations involved in major accidents, see the court report of the Zeebrügge and Clapham Junction cases (Rasmussen, 1993).

DESIGN OF WORK SUPPORT SYSTEMS

One of the Hopkins' conclusions is that in the age of computers it is easy to disseminate information and to make sure it is available to all relevant personnel through a shared decision support system. In other words, a shared information system should serve to couple the information environments facing decision makers in several organizations, at different levels of society, being active at different point in time during normal work, not to wait for the coupling through accidents as discussed previously. Rather than to rely on a n empirical culture based on oral or written information, decision support systems should be developed to support adaptation to safe cognitive and meta-cognitive aspects of performance. This should be possible by embedding constraints upon communication through integrated information- and decision support systems so as to reward evolution of cooperative 'professionalism.'

The central issue for design of such a support system is to apply a functional abstraction perspective and to make sure that the proper information flow channels downward and upward the socio-technical system of Figure 1 are intact. From a control perspective, this raises the following questions for each level of decision-makers:

– Are objectives, intentions, and performance criteria known and communicated effectively among the decision-makers and formulated at a level and in a language matching their task. Will they be used to judge performance in stead of prescriptive rules?
– Are actors supplied with reliable information on the actual state of affairs within their action domain in a form that is directly comparable to the formulation of objectives? Can the state of affairs be verified with reference to target states without detailed analysis? Is the correspondence directly visible?
– Are the boundaries of safe operation visible in a way that will catch their attention during their normal work, and are cues available to draw attention to changes in the normal work conditions? Furthermore, is the influence on the boundaries from decisions made by the other actors within the socio-technical system adequately represented? To meet these

conditions, an explicit formulation of the preconditions of safe operation for the particular installation must be available at each level of the socio-technical system.

For this purpose the preconditions and assumptions of a predictive risk analysis (PRA) must be explicitly stated. It is no longer acceptable that predictive safety analysis is considered an art. (Amendola, 1989). A further development of PRA toward an operational management tool is required. Fortunately, it is not necessary for this purpose to predict performance of operators and management. When a plant is in operation, data on human performance in operation, maintenance, and management can be collected during operation and used for a 'live' risk analysis.

– Next, are the actors competent? Several questions become critical, when interpretation of generic regulation is delegated to local decision-makers. Are they thoroughly familiar with the control requirements of all relevant hazard sources within their workspace? Do they know the relevant parameters sensitive to control actions, and the response of the system to various control actions?
– And finally, are *priorities* right? Will decision-makers be committed to safety? Is management, for instance, prepared to allocate adequate resources to maintenance of defenses even when no incidents have taken place? Do regulatory efforts serve to control the management priorities properly? This question also points to the influence of different time horizons of market dynamics, personal career planning, financial forecast, and protection against major accidents.

This discussion shows that for effective decision support, the design of decision support systems should be based on a functional analysis of the particular work system. This analysis should include an explicit identification of the boundaries of safe operation, together with an interface design that makes the state of affairs with respect to the boundaries directly visible. The problem is not to match an interface to the mental models of the operators but to design an interface that forces operators to adopt a faithful mental model of the workspace and offers a visual representation for direct perception and manipulation of system states.

This is the objective of ecological interfaces design (Rasmussen and Vicente, 1989, 90; Vicente and Rasmussen, 1990, 92) and has been successfully applied at the lower, productive levels within process control (Flach et al., in press) and aviation (Rasmussen, 1999). The application of such ecological displays at the higher organizational and regulatory levels is an important research issue.

CONCLUSION

The basic message in conclusion of this discussion is that to improve risk management in a dynamic, competitive society, attention should be turned from analysis of past accidents and 'human error' toward analysis of normal work practice. This analysis should identify the control requirements of the hazard sources and the risk management strategy to be considered during design of effective decision support systems. Furthermore, risk management should not be the responsibility of a separate safety organization, but an integrated part of the criteria guiding normal, operative management.

Considering that operators are present to complete the design during unforeseen situations and given the findings from accident analyses, an improved communication must be established from the initial, conceptual system design, to system implementation, and to system operation. In particular, the preconditions and assumptions underlying the predictive risk analyses underlying system acceptance must be made explicit since this information defines the boundary of acceptable operation at all levels of the socio-technical control system.

Unfortunately, designers of decision support systems pay only little attention to the communication of intentional information to system users. The reason for this is that the rationale for most design choices has been embedded in the minutes of meetings, in professional and company practice and in industry standards and it is often very difficult to identify and make explicit the original reasons for a particular system design feature. Blueprints and operating instructions only communicate *what* and *how,* not important information about *why*. Formulation of the boundaries of safe operation in a form that can be used for the decision support systems to serve operational management will involve a kind of 'reverse engineering' involving the conceptual system designers (this approach is discussed in Tanabe et al., 1999).

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CHAPTER THREE
Cultural and National Factors in Nuclear Safety

NEVILLE MORAY

Cultural and national characteristics are examined at three levels of nuclear power plant design and operation. It is shown that at each level, ergonomics, control room organization, and national characteristics of the workforce there seem to be substantial differences that have potential impacts on nuclear safety and productivity. The implications of such differences are discussed in the context of recent work on high reliability organizations. Cultural can significantly affect the safety of complex technology such as nuclear power plants when they are exported, and may affect international assistance in hazard management.

Moray (1999) gives examples of differences between cultures from the point of view of ergonomics of safety in the theme further and enlarged in scope. Many countries possess or are developing nuclear power industries. At the start of the 21st century there are nearly 450 nuclear power reactors world-wide, and there is now a mature industry to export designs, plants, and operating practices from one country to another. There are also plans for experts from one country to assist those of another in times of accidents and hazard management. However, although there are but a few types of commercial reactors, and even fewer which have a successful commercial market, there are many differences among utilities in the implementation of engineering designs, in operating procedures, in recruiting practice, in training, in regulation, and in their safety culture and other aspects of organization and management.

Such differences may be accidental; but it is also possible that there are systematic differences among cultures and countries which embody different values and philosophies, and which may have an impact on safety and productivity in the nuclear industry. Unfortunately a search of several hundred entries on the Internet using indices such as ”nuclear power” and ”culture and nationality” revealed almost no information of interest. There are a few (rather old) documents from the US Nuclear Regulatory Commission that provide some comparative material for Japan and the USA, there is a paper by Rochlin and von Meier (1994) which compares practices in several European countries, and there is some relevant material in Misumi, Wilpert and Miller (1999), especially the paper by Bourrier (1999). Otherwise there is little research that looks explicitly at differences in the operation of nuclear power plants (NPPs) from the perspective of culture and nationality. The main thrust of this paper must therefore be to raise questions rather than to present a complete case for the importance of cultural and national differences.

We shall consider three kinds of evidence which suggest significant differences in the way that people behave that may be due to their culture (in the sense of nationality). Such differences mean that inadvertently safety may be compromised (and in some cases definitely will be reduced) in technology transfer unless account is taken of these differences. Behavior will differ in response to similar events as a function of nationality.

It has become a commonplace of system design philosophy since the accident at Three Mile Island that to design, construct and operate NPPs we need an integrated systems approach, in which architecture, engineering, human interface ergonomics, procedure writing, personnel selection and training, and managerial philosophy should be tightly integrated. The factors to be discussed all suggest that even if such integration is achieved in one culture, the export of a ”turnkey” NPP system from one culture to another may be sufficient to weaken the integration and reduce safety.

BASIC ERGONOMICS

As Moray (1999) pointed out, there is ample evidence that people’s expectations differ widely across cultures about how displays and controls are related. The most obvious example is the operation of electrical switches. To North Americans, a circuit is live if the switch controlling the flow of current is in the ”up” position: to a European it is live if the switch is ”down”: and to a Japanese a circuit is live if the switch has moved from the left to the right. Swain and Guttmann (1983) predict that even within a culture there is a non-trivial probability of moving a switch in the wrong direction, especially when working rapidly under stress. If throwing a series of switches, the probability that others will be thrown incorrectly if the first one is thrown incorrectly is greatly increased. Fleishman and Buffardi (1999) put the probability of error if a control has to be turned against the expected stereotypic direction as high as 0.15. Consider the case where a component purchased from one culture is embedded in equipment from another culture, which may well happen when components are bought in to synthesize a system from existing commercial sources. When operating rapidly in an emergency, the probability that cultural stereotyping will carry over from the ”domestic” to the ‘foreign” component will certainly be high, and the probability of error greatly increased.

Although several cross-cultural studies of basic ergonomics of this kind have been performed (Chapanis, 1975), our knowledge of the extent of cross-cultural differences and their strengths is not presently adequate to support safe design. Some think that with the computerization of controls and displays this problem will disappear, but that is by no means certain. For example, keyboards for identical computers are still different in different countries, and there is no sign that they will become identical. Although there seems no published research on the topic, it is not impossible that national stereotypes for the semantics of color and forms of icons may be strong enough to cause problems. Since eye movements during reading differ as a function of the native language of the reader, we may well expect that the sequence with which different parts of displays are scanned may be significantly different even when using computer-generated displays. Furthermore, if in pursuit of employment in the nuclear industry there is a significant movement of personnel across national boundaries keyboard skills may be sensitive to cultural stereotypes. An English person using a French keyboard is highly error prone even after several years, particularly if the different keyboards are used concurrently for different tasks (personal observation). Contrary to what an American human factors authority has suggested (Van Cott, 1995, personal communication), there is no evidence that a single keyboard is becoming adopted internationally. Research on stereotypes and error suggests that it would probably be inadvisable to attempt such a standardization.

As Moray (1999) reported, some stereotypes seem to be fairly universal, but others show considerable differences between countries. Among the control-display relationships for which there are either very strong differences, or (what is equally a problem) no strong stereotypes, are the following: labeling of quadrants of a circle, numbering of keys from 1 to 10 across the fingers, and direction of turning pairs of rotary controls (such as taps). While it is always possible that intense training will overcome a national stereotype, it will not abolish a tendency to revert to type when behavior becomes skill-based rather than consciously directed.

An interesting example of a cultural stereotype at the level of control panel ergonomics is reported by Rochlin and von Meier ((1994). In a Swedish nuclear power plant the personnel insisted on changing the color coding of all the lights on the panel to green versus white rather than the original colors provided by the manufacturer.

CONTROL ROOM HIERARCHY

A second kind of cultural (rather than national) difference is control room organization. Figure 1 is taken from Moray (1999). It shows the very wide range of organization found in control rooms. While some differences can be put down to the kinds of reactors represented (Pressurized Water Reactors, Boiling Water reactors, Heavy Water Reactors), that cannot explain cases where a different style of organization has been developed for the same type of reactor. Rather such cases represent differences in organizational philosophy, both within and across national boundaries. These in turn may reflect differences in training and education of the workforce—for example only the USA can currently draw on a large nuclear navy as a recruitment pool—or of national regulatory practice and its interpretation by utilities.

Apparently all these types of organization can be used satisfactorily to operate NPPs, but one must wonder whether they are all equally effective, and about the extent to which they embody unspoken assumptions about authority, communication, social and professional hierarchy, etc.. A clear case of a national difference is the position of the Safety Engineer in Type 1 and Type 6 control rooms. The US NRC mandates the first, the latter is French. While there is apparently no evidence that one form of organization is significantly better than another, one may again expect that if personnel were to transfer between organizations there would be problems of co-ordination.

HIGH RELIABILITY ORGANISATIONS

These problems are important because in the nuclear power industry we are concerned above all with safety, particularly after the events at Three Mile Island and Chernobyl. If nuclear power is to be acceptable, it must be perceived by the public to be safe as well as economical. NPPs are exceptionally complex, and it has been suggested (Perrow, 1984) that such technologically complex systems will inevitably have accidents. To avoid accidents technological system must be as reliable as they are complex.

What, then, are the characteristics of outstandingly safe technological systems? One approach to an answer may lie in the recent studies of the Berkeley group concerning what makes highly complex, technological, hazardous systems perform with an exceptionally high degree of reliability (Roberts, 1990, 1993; Rochlin, 1999; LaPorte, 1996). These researchers have investigated several organizations which show unexpectedly high levels of reliability. The systems are complex, involve high technology, have characteristics which mean that there are high hazards involved, and in some cases which make one anticipate high levels of risk. Yet they have extraordinarily low levels of faults and accidents. Since we are, in the nuclear industry, concerned exactly with systems which have all of these characteristics, and since we wish to ensure that the last, above all, is true, let us consider the generalizations about such systems provided by those authors. Unlike Perrow (1984) these authors do not analyze the response to accidents and the causes of accidents, but rather the characteristics which lead to the *absence* of accidents.

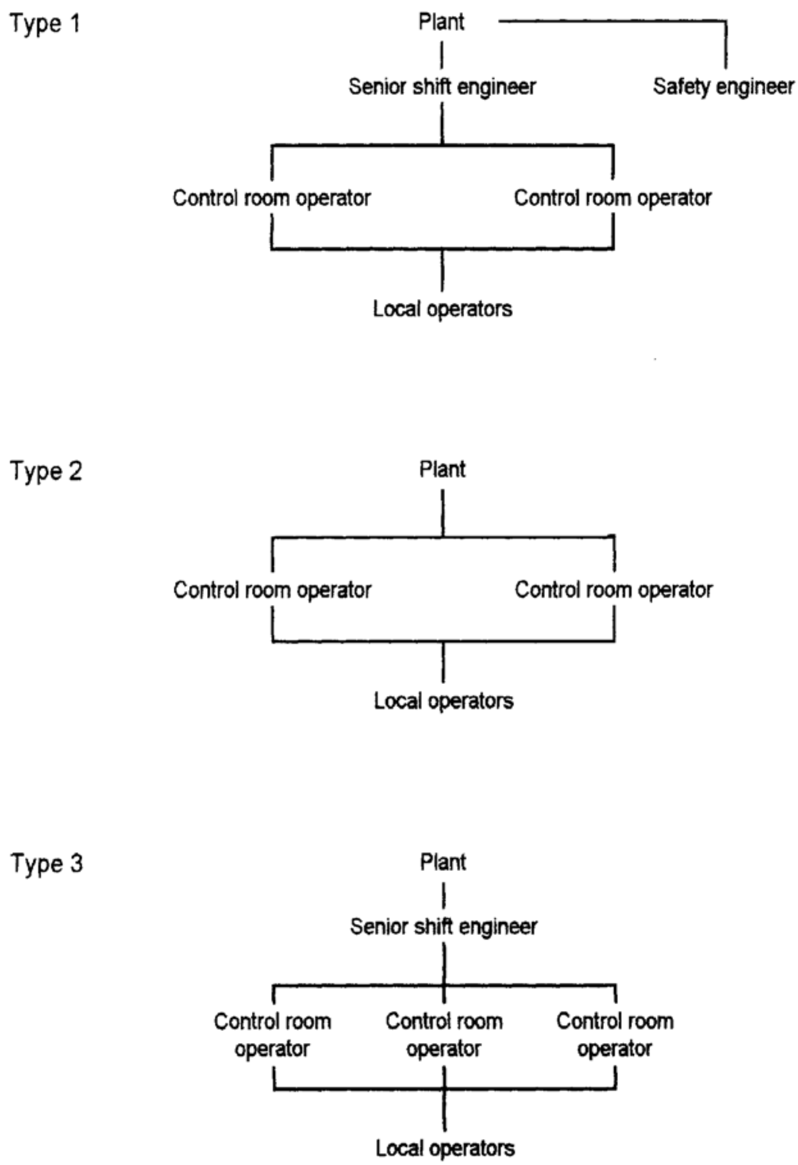
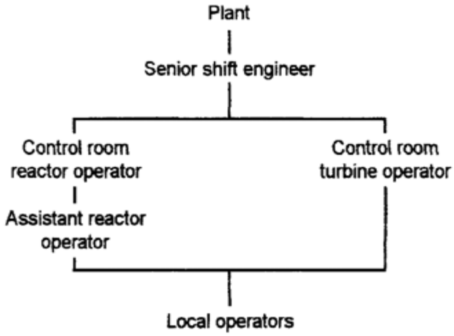


Figure 3.1 Examples of control room organisation

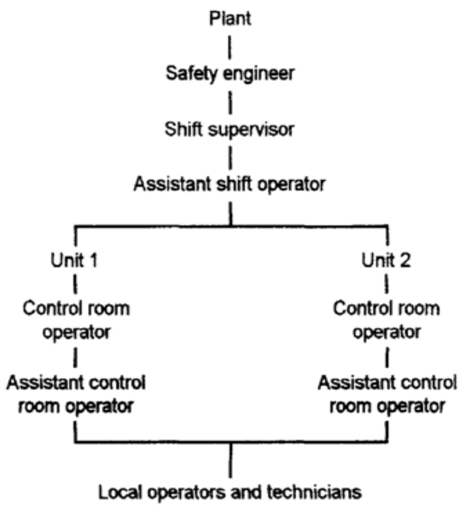
From LaPorte (1996) we can deduce the following of the characteristics of high reliability organizations (HRO).

Type 4



Type 5

Type 6



1 The design of such systems cannot be based on ”trial and error” because the cost of error is too great (and in some cases there are no precursors).
2 HROs’ central day-to-day preoccupation is to operate complex, demanding technologies without major failures, while maintaining the capacity for intermittent periods of high peak activity which push the system to its limits.
3 They are characterized by a strong and clear sense of mission and operational goals to provide service and reliability, and this can lead to what the authors call a ”domain consensus”, in which the system is accepted as a necessary part of the modern society.
4 Such systems are characterized not merely by high levels of advanced technology but also by a tight coupling of technical and social relationships.
5 HROs are marked by a very high level of technological competence. There is a very high level of technological knowledge of the system and its components, high levels of performance, and highly developed understanding of the system’s operating state at all times. This implies that any interfaces must be particularly transparent to the users. Operators must be able to see the state of the system clearly.
6 HROs ,make activities which enhance reliability, including easy access by lower grades of personnel to senior levels of management to report problems, particularly easy to see for those involved.
7 Accessible quality assurance data bases that allow the state of the plant to be tracked and calibrated at all times are constantly maintained, so that there is an unambiguous description of system state available.
8 The organizational style provides a high degree of flexibility and ”organizational slack”. People are trained to perform many functions, not just one specialized one, so that there is structural flexibility and redundancy. (Indeed running through their description of all HROs which have been examined is the need for organizational and staffing redundancy, not just technological redundancy, to ensure reliability.)
9 HROs show ”organizational recombination” in the face of unexpected events (”technological surprises”), an ability to self-organize to meet new demands, and to devolve and change the patterns of authority to meet the demands of the events. Organizational hierarchies and heterarchies are flexible rather than rigid.
10 There is a sense of collegiality and shared responsibility. The pattern and devolution of authority at any moment is a function of the distribution of skills, and this changes functional authority relationships from those which are formally represented on paper. As events pass and revert to normal, so does the hierarchy and distribution of authority. ”There are well practised, almost scripted, relationships activated during acute emergencies.”

11 Decision making is dispersed, and need not be referred to a central authority.

12 Once made, decisions lead rapidly to action, and with little chance of re-thinking. (This is often required by the dynamics of the events.)

13 There is a constant search for improvement in safety and reliability. This is often done by having groups of people whose job officially is to look for problems and signs of weakness in the organization. If there is a long period when no incidents occur, this tends to be seen as a sign that standards may have been reduced, rather than that all problems have been solved.

14 The reporting of errors and faults is rewarded, not punished, and mechanisms are in place to ensure that lessons learned from such errors are transmitted to the upper levels of the management hierarchy.

LaPorte, Rochlin, Roberts and their co-workers talk of a culture as, ”… shared perceptions, workways, and informal traditions that arise within the operating and over-seeing groups”. Crews have ”an intense élan” which takes them far beyond their formal role specifications. Operators and crew have a high degree of discretion in the actions they can take, and the tensions which occur between engineers and operators are resolved by real time negotiations about what characteristics are most needed for a particular incident from moment to moment.

The great emphasis which the Berkeley group places on organizational, as against purely technical quality is shown by the following quotation:

> ”The external support for achieving the internal conditions of trustworthiness is perhaps the most important of all the properties of HROs…and without them the rest are difficult to achieve and sustain.” (LaPorte, 1996, p. 65)

This refers to external relations with other bodies. Formal public relations with stake holders both in the industry and in society in general, both local and national, and with user groups, regulators, and other checking groups, must be open and well developed. Arrangements must be made to ensure that information crosses the boundaries from the system to external stakeholders, and

> ”Tasks should be carried out in ways that, as the public become aware of internal processes, they discover activities that increases (sic) institutional trustworthiness rather than decreases it.” (quotation from a US DOE document: LaPorte, 1996, p.68)

For the nuclear industry, an understanding of the factors and conditions which give rise to and support HROs is of central interest, but two obvious questions can be posed about the work of the Berkeley group. Do their generalizations apply across a range of industries? Do they apply across cultures? The published reports of Rochlin, LaPorte and Roberts were based originally on studies of a nuclear aircraft carrier, a nuclear power plant, and an air traffic control system, each of them American, and it seems that the list of HRO characteristics cited above is biased towards their findings from the aircraft carrier. While some characteristics, such as the need for a ready flow of information, self-reporting or errors and a high degree of professionalization could readily apply to the nuclear industry as a whole, there are other characteristics which seem less likely to transfer. To see some reasons for this let us examine some of the empirical findings of cross-cultural studies.

NATIONAL CHARACTERISTICS

Regulation and culture

There are wide variations in the form of regulation. A striking difference is between the highly prescriptive style of regulation which has been typical in the past of the USA, and the more flexible performance-based pattern in, say, the United Kingdom.

Although there is evidence of a change in recent years in the USA towards performance based regulation, especially in the context of modernization and plant life extension plans, traditionally US regulation of NPPs was by prescription, in the sense that attempts were made to specify exactly what forms and functions had to be met by vendors and utilities, and hoe operators should behave in all situations. Regulation was prescriptive and rule based. In the UK, by contrast, regulation is fairly flexible, in the sense that there are not very precise and detailed specifications which the utilities must meet. Instead, general rules and goals are specified, and it is up to the utility to convince the regulators that the solution they have adopted is safe, that the ”Safety Case” is convincing. In principle this can lead to quite varied solutions for control room design, operating practice, and management philosophy.

It is interesting to speculate whether countries (such as the USA) which have a written constitution as the basis for society’s laws tend to prescriptive regulation, whereas countries (like the UK) with no written constitution but law based on case law favor regulation on a case by case basis, governed by overall general principles. This notion is supported by Rochlin and von Meier (1994). They note that the US regulatory style is highly ”command and control”, prescriptive, and requires arms’ length relationships between regulators and the industry. By contrast, European regulatory practice aims both to regulate and to provide support to good operating practice. They describe the latter attitude as one of saying, "We will not look over your shoulder to verify constant compliance; but if you break the rules and break the plant, you are in big trouble." They describe a case of management and operators discussing how important a particular violation of standard procedures might be, and state that such a discussion would be inconceivable in the USA.

While most countries have a single regulatory body, Japan does not. Instead, two government ministries, the Ministry of Science and Ministry of International Trade and Industry (MITI) share the responsibility for ensuring safe operation of reactors.

The UK Health and Safety Executive, in a recent document on the regulation of industrial health and safety at work in general, (not particularly in the nuclear context), found a difference between large and small organizations. In the United Kingdom large companies are content to have to prove safety cases, so that they have a large amount of flexibility in finding solutions which fit their particular organizations. Small organizations seem to find the burden of devising solutions and proving them safe to be too great, and have recently requested more prescriptive regulation.

Degree of Automation

As is well known, the degree to which the instrumentation and control is computerized, and more importantly, the amount of automation used in control, differs considerably among nations. The most striking difference is between the relatively slight automation and few computerized control rooms of the US nuclear industry, and those of many other countries. To some extent this difference has historical reasons. The US reactors were developed from naval reactors, and strongly influenced by a philosophy of control room organization and behavior coming from their military origin and the influence of Admiral Hyman Rickover. There was a belief that human operators were more reliable than computers at the time that the US industry was created. On the other hand, for example, the Canadian CANDU reactors were developed *ad initio* on the assumption that well designed computer control is more reliable than operators. It is worth noting that the computer codes of the CANDU reactors are rather simple and straightforward, and while there is complete digital control of the reactors, there is little or no artificial intelligence involved.

Although the difference between US and Canadian design is often cited as due to attitudes to automation, Carter and Uhrig (1990) note that automation was to a large extent forced on the Canadian designers by the dynamics of natural uranium heavy water moderated reactors, which require much more active control than do PWR or BWR light water reactors, particularly to control xenon poisoning. However, these researchers also note some significant cultural characteristics of the CANDU plants. In Canada the operators were involved in the design process and thoroughly trained on digital instrumentation and control before the latter were introduced. We should also note that selection and training is very different because of the absence of a Canadian nuclear navy, and that it takes up to 7 years to become a shift supervisor in Canada, during which time potential operators are not only trained in operating reactors, but also work in all parts of the utility operations, including field maintenance of the grid, etc..

More recent PWRs and BWRs throughout the world have been increasingly automated, and future systems will undoubtedly take automation for granted. Rochlin and von Meier (1994) however, in their comparative study of NPP operations in the USA, Germany, France, Switzerland and Sweden found that operators in all of those countries were united in rejecting the idea of complete automation. On the other hand, they concluded that,

> ”An intensive study of France and Germany showed variances between operators and maintainers of highly automated production technologies were determined almost entirely by differences in national culture rather than work or job status.” (Rochlin and von Meier, 1994, p. 161)

A particular case quoted by these authors is that of ”télépilotage”, the control of the plant from remote sites due to demands for power at different parts of the grid. In general operators resisted the idea that off-site power distributors could control the power output, and managed to limit the rate at which power could be ramped to well below that which they could achieve locally at the control panel.

It was clear that European workers felt much more at ease with automation and computerized systems than did the American operators. There was much less trust of computers and automation in the US plants than in European plants. It should be noted that there are no US plants which have been designed from the start for fully computerized display and control: at best there are some computer displays, and recently there is discussion of retrofitting computerization to deal with the problem of plant life extension. By contrast, Canadian, Japanese and many European plants have been designed from the start for highly automated computerized operation. It is not surprising then that such differences exist.

Communication

Several countries have a potential for problems of communication due to linguistic differences within their populations. At Wylfa in the United Kingdom, for example, the day to day language of many of the staff is Welsh, while staff who are recruited from other parts of the United Kingdom are not Welsh speaking. The policy adopted at Wylfa is that staff can use Welsh for most purposes, but during formal communications involved in plant management English must be used. (A comparable situation is found in Air Traffic Control, where communication between ground and aircraft must be in English, while conversations among flight crew or among controllers can be in national languages.) There have been no problems reported arising from bilingual operations in the Welsh NPPs.

CULTURE, NATIONALITY, AND NUCLEAR POWER OPERATION

Boegel, Chockie, Huenfeld, Morgenstern, and Olson (1985) compared organizational and maintenance practices of US and Japanese plants, at a time when the availability of Japanese plants was very much higher, and the unplanned trip frequency much lower in Japan than in the USA. They found a much greater emphasis in Japan on extensive and continuous planned preventive maintenance going voluntarily beyond required mandated maintenance, that many more types and elements of components were examined in Japan during maintenance, and that there were characteristics of Japanese culture which had an impact on maintenance, and on the high availability of Japanese plants. Maintenance in Japan uses teams of workers who are cross-trained so that jobs are rotated, and it is the teams that are responsible for the quality of the workers performance. In the US workers tend to be trained for particular jobs, and quality control over the individual worker is exercised by a person at a higher level of authority who is not carrying out the work. These researchers make two comments that are interesting in that they point to the possibility of general national cultural characteristics being important.

> ”The group orientation of the Japanese society in combination with the Japanese system of labour relations impacts the way maintenance activities are structured and carried out.”.” (Boegel et al., 1985 p. 2–2)
>
> ”The group orientation of the Japanese society to an important extent determines the form and practice of management and organisational structure.” (Boegel et al., 1985 p. 2–2)

They note also that in Japan there is a very close and strong relation between utilities, vendors, and subcontractors, and that because of the culture of loyalty to the firm and loyalty to the employee, workforces tend to be stable, and vendors are locked into close social relations with the utilities, quite apart from the contractual relations,.

Rochlin and von Meier (1994) list both similarities and differences among practices in the US and in several European countries, restricting their study to PWRs between 900 and 1300 MW in Germany, France, Switzerland and Sweden. The similarities they note include the fact that tasks such as operation, maintenance, nuclear physics, instrumentation and controls, and engineering were separately organized and administered, and that in all countries trainees underwent a period of ”apprenticeship” training following the formal training. They report that in all plants people at all ranks felt responsible for safety, and that there was always a ”relentless striving for perfection”. that amounted to a safety culture. In all the countries engineers tend to think of the plant as an abstract structure which is state invariant, while operators tend to think of plants in terms of process, as time varying, and as having individual ”personalities”. In all plants there tends to be tension between engineers and operators, requiring negotiation between the groups as to which is more relevant in a particular incident.

Differences which they noted include the style of regulation, the degree to which people are trained for only one job or are trained to rotate through many jobs, and the degree of acceptance of and confidence in computerization. There is also great differences in social styles of operation. In some plants hats or uniforms must be worn, in others hats are never worn and there are no formal uniforms. In some European plants a relaxation room which contains a television set is provided adjoining the control room; in others a kitchen is provided for the use of the operating crew.

The exact significance of these differences is not known. One is reminded of Bourrier’s work on maintenance, where she suggested that,

> ”Many (of these differences) are related to mutual trust and confidence, others may also interact with larger issues such as regulatory compliance and approaches, still others may be purely a matter of interplant cultural symbolism.”

Clearly such differences reflect differences in expected patterns of behavior, and if we take this together with the differences in control room hierarchy organization described in an earlier section of this paper, we would expect non-trivial differences—perhaps particularly when operators and engineers from one culture are injected suddenly into another culture in well-intentioned efforts to assist the latter in times of crisis.

National factors are also present at the level of the political commitment by the government to the industry. Boegel et al. (1985) state that at the time of their report there was a much greater commitment by the government to support the industry in Japan because of the lack of significant natural sources of energy to support Japanese industry in general. The government offered financial inducements to communities to accept NPPs, and thermal discharge from NPPs was being used to support fish farming, all this being subsidized by the government[1]. While such interaction between the government and industry is seen as quite normal in Japan and in some European countries, it is of course most unusual in the USA where the political culture has a particularly strong emphasis on private enterprise and a traditional suspicion of government intervention.

Since the time of the Boegel et al. studies there have been marked changes in national cultures. The 1990s have seen a weakening of the culture of lifetime employment in Japan, and increasing privatization of industry in Europe. However, for anyone who travels extensively, the existence of very strong cultural differences is immediately evident. Whence do they come?

Theoretical Interpretation

It is obvious that at some level, and in some way, national differences are the result of social learning and aculturalisation. Hofstede (1980, 1991) has described culture as the collective programming of the mind that distinguishes the members of one group or category of people from another. He proposes that symbols carry meaning which is only recognized by those who are members of the culture, and that ”the core of culture is formed by values”, values that are broad tendencies to prefer certain states of affairs over others, and which have valence. It would not then be surprising if patterns of organizational behavior were significantly different in different cultures, to the extent of affecting attitudes to efficiency and risk in the operation of high technology systems. Even the way research is done and interpreted may differ, since culture will affect both which research projects are considered worthy of support and how research results are understood, perhaps above all in behavioral and social sciences.

Two American studies, by Osborn, Olson, Sommers, McLaughlin, Jackson, Scott, and Connor (1983) and by Marcus, Nichols, Bromiley, Olson, Osborn, Scott, Petto, and Thurber, (1990) suggest a series of generalizations about organizations. The larger the nuclear organization, the more mechanistic will it be and the less will be the emphasis on quality; the more mechanistic and the less good at ”employee maintenance” (i.e. industrial relations between management and workers) will be the organization; the more likely it will be that rules will frustrate innovation; and the more individuals will tend to emerge to take charge of innovation. Also, the better the technology the more diverse will be the organizational design and the greater the emphasis on quality, the greater the emphasis on innovation, the lower the efficiency (in profitability terms), and the lower the compliance (with regulations) record. (Curiously this seems to suggest that advanced technology will tend to produce violations of regulations. Furthermore the claim that profitability will be lower seems strange.)

Marcus et al. describe job design and job allocation as something very precise which can be represented by a rigid figure such as a hierarchical tree. It would seem that organizations that fit such a description would virtually preclude cross-training such as is seen in Japanese industry. They found that US plants with a large number of vertical ranks, many departments, and many subordinates per supervisor usually performed better.

Those who are familiar with organization and work practices in different countries may feel that such generalizations are characteristic of US NPPs, and the US philosophy of industrial relations, but are probably not generalizations that are applicable to all, or even many, other countries.

Are there then re major national characteristics that can be linked to the organizational characteristics of industries, including nuclear industries, and if so, are such differences are of sufficient magnitude that it may even be unsafe to carry recommendations for practice from one culture to another?

The evidence discussed above reveals considerable variations in the way in which control rooms are designed, NPPs operated, and nuclear organizations managed. It does not necessarily follow that the differences are due to cultural differences linked to nationality. It is tempting to conclude that such differences exist, but it is possible that differences between corporate practices, between economic pressures, between types of reactor, or the times at which the NPPs were constructed could account for many of the observed differences. Many such variables have been discussed by Reason (1997). There is, however, at least one study that controls, to some extent, for many such factors.

Cultural Differences in Personality?

Hofstede (1980, 1991) studied the attitudes and values of employees in a single organization, IBM[2], which has branches in many countries around the world. It recruits people locally to work in those branches from a somewhat uniform educational and social background. Regardless of the country in which the branches are located, similar work must be done, to similar standards, and within a single corporate culture and philosophy. To some extent many of the cultural differences have been at least partly controlled, leaving nationality as a major independent variable.

Hofstede's work revealed several major dimensions of attitudes which have potential importance for the safe operation of hazardous high technology systems, and which certainly can be expected to have an impact on organizational relations and communication within such systems. Hofstede claims that his work gives a picture of differences among locations, rather than about individuals, but also notes that because of the job structure at IBM it is a picture of national differences among what are broadly middle class populations, and may not apply to other levels of society.

Among the main dimensions which Hofstede extracted from his data by factor analysis the most relevant indices or dimensions are the Power Distance Index (PDI), Individualist/Collectivist Index (ICI), and an Index of Uncertainty Avoidance (UAI). The data were collected using questionnaires and were administered to IBM employees in more than 50 locations round the world. There were common problems to be solved in the operations of the IBM corporation, but the kinds of solutions adopted in the day to day running of the company differed from location to location. Hofstede's intent was to relate these differences in practice to differences in attitudes along the dimensions he reported.

Power Distance Index

Hofstede interpreted the PDI as a measure of attitudes to authority, and of the extent to which people felt free to take responsibility for action, and to relate to others and to values of their own personality and life in general. Those who scored high on the PDI saw their relations to authority, in particular managers, as being distant. They were more unwilling to express disagreement with managerial decisions, saw their superior's attitudes as being either autocratic or paternalistic rather than consensual, and also often *preferred* autocratic or paternalistic styles of management to the consensual and participatory. The emotional distance between employee and management was felt to be large. (This somewhat resembles the "authoritarian personality" described many years ago by Adorno and Frenkel-Brunswick (1950). By contrast those scoring low on the PDI show less dependence on superiors, greater preference for consultation, and a smaller the emotional distance, i.e. a greater preference for *inter*dependence.

The picture is complicated by the fact that in organizations with high PDI subordinates may either prefer or alternatively strongly reject interdependence. That is, PDI is a polarizing attitude. The higher the PDI the greater the extent to which the less powerful members of the institutions and organizations will tend to consult experts rather than taking their own decisions; and they will accept the fact that power is distributed unequally. In low PDI organizations employees will offer more suggestions and propose innovations. They can then be expected to show more independence and initiative.

PDI scores are higher in jobs requiring lower levels of skill, and the national differences were less among lower skilled workers. Locations with PDI scores in the top third of the ranked order included Malaysia, Philippines, India, Singapore, France and Hong Kong. Those in the middle third included South Korean, Taiwan, and Japan. Those with the lowest scores included the USA, Canada, Netherlands, Scandinavian countries and the UK.

Hofstede drew attention to differences in managerial styles that seem to correlate with these national differences. The USA has a moderate to low PDI score (40 on a scale of 0–100), and typically has a management style in which there is considerable collaboration of employees with management, but largely at the discretion of management. In Scandinavian cultures equality and consensual decision making is often enshrined in legislation as well as in psychological attitudes. In Greece, with a PDI of 60 on a 100 point scale,

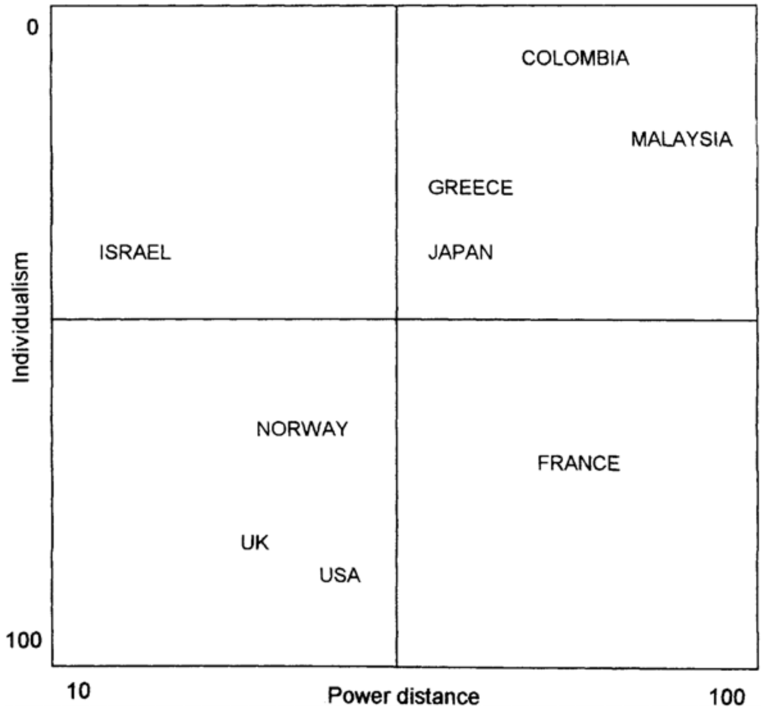


Figure 3.2 Some examples of the relationship between Power Distance Index and Individualism/Collectivism Index. The ratio of Individualism to Collectivism increases downwards on the ordinate (adapted from Hofstede, 1991).

Hofstede reports attitudes as being typically, ”If he is the manager, why should he want consult my opinion—he should know what to do.”

Individualist/Collectivist Index

Hofstede’s second dimension is the ICI, which describes the extent to which a culture sees personal identity as based on the individual or alternatively in the social group. He notes that during early education, the difference can be seen in the extent to which children are taught to think in terms of ”I” or ”we” as a source of values, related to the individualist nuclear family rather than the extended collectivist family. (In most Western countries birth certificates primarily mark the individual’s identity: in Japan the equivalent document (the ”family register”) identifies a person as a member of a particular family.)

In countries with high ICI scores, that is individualistic cultures, personal time is demanded for self and family life, there is considerable freedom to adopt an individual’s own approach to a job; and challenging work gives a sense of accomplishment. In collectivist cultures the good of the group is perceived as paramount. In cultures with low ICI scores people see training as a means of acquiring job related skills rather than for self-advancement, and hope for training opportunities. They put an emphasis on good physical working conditions, and make use of skills and abilities on the job. Note the difference between learning, which benefits the individual, and training, which benefits the collective job performance. The collectivist sees training as a means to exercise skills for the common good (team, company), wants good working conditions, and prefers well organized collective rules and organizational control, not initiative and innovation.

There are some complex relations between PDI and ICI scores. In the richest and poorest countries Hofstede found a strong inverse correlation between PDI and ICI, which was not present in economically middle ranked countries. There was also an interaction with occupations. For example, within occupations the sense of challenge and the use of skills correlate positively, but between countries the correlation is negative. Those countries in which challenging jobs are felt to be fulfilling tend not to express a positive attitude to skills training; but jobs which are challenging, across countries, tend to show employees valuing training. This rather subtle difference seems to support Hofstede's claim for the existence of national cultural characteristics. Figure 3.2 shows the location of countries in the PDI/ICI space.

The ICI index has a number of practical implications. In a country with high ICI, workers will tend to be hired for their individual skills (and, although Hofstede does not discuss this, presumably promoted for their individual skills in a competitive way). But in countries with low ICI, there is much more emphasis on hiring people who will be loyal to the firm, who will put the good of the firm above family pressures, etc.. Furthermore, there will be more emphasis on training in firms from low ICI countries. A selection of the typical characteristics of individualistic and collectivist cultures are, according to Hofstede, as shown in Table 3.1. (The table in the original source includes more information.)

Countries with high ICI include the USA, UK, Canada, Netherlands, the Scandinavian countries, France and Germany. Those with intermediate scores include Japan, India, Brazil and Greece. Those with low scores include Singapore, Hong Kong, Malaysia, South Korea, Taiwan and Pakistan.

In collectivist cultures much is taken for granted—in individualist cultures communication must be explicit: for example American commercial contracts are much more detailed than Japanese ones. It would be interesting to see whether the style of operating procedures is reflected in this, or, perhaps even more interesting, to observe whether as Japan begins to build and export reactors, the operating procedures and emergency operating procedures are different in style from those of the USA and the UK. Hofstede cites an interesting experiment that suggests that defining jobs in terms of

Table 3.1 Characteristics of collectivist and individualist culture

Collectivist	Individualist
Collective interests prevail over individual interests	Individual interests prevail over collective ones
Opinions determined by group membership	Everyone expected to have a private opinion
Dominant role of state in economic system	Restrained role of state in economic system
(Political) power determined by interest groups	Economy based on individual interests
Press controlled by state	Press freedom
Imported economic theories largely irrelevant because do not support collective interests	Native economic theories based on self-interest
Ideologies of equality	High value of individual freedom rather than equality
Harmony and consensus in society are ultimate goals	Self-actualization of individuals the ultimate goal

ICI factors may have practical implications. When manufacturing baskets to the same productivity goal it was found that Chinese workers worked best when the goal was a collective one (200 baskets to be made by a team of 20 people). American workers worked best when 20 workers were given the goal of 10 baskets each.

Uncertainty avoidance index

This index measures the extent to which members of a culture feel threatened by uncertain or unknown situations (it is not the same as risk avoidance). High scores were found for Japan, South Korea, and France; intermediate scores for Norway, Canada, USA, Finland and Germany; and low scores for UK, Hong Kong, Sweden and Denmark.

Countries with a high UAI tend towards a proliferation of rules and regulations. There is a relation with PDI, since if PDI is large, the power of superiors can substitute for explicit rules. In high UAI countries even ineffective rules can satisfy the psychological need—for example in France under the ancien régime there was a saying, ”une règle rigide, une pratique molle”. (It is interesting in this light that much of the misunderstanding between the UK and France in the discussion of EU laws may stem from the British belief that laws are meant to be followed exactly, whereas France still in some respects operates on the rules of the ”ancien régime”.) Collectivism tends to be associated with uncertainty avoidance, as does an emphasis on rule and law following. There may also be a relation between UAI and the tendency toward long term planning. The rank order for long-term planning included China(1), Japan(4), Sweden(12) Germany(14), USA(17), UK(18) out of 23.

DISCUSSION

One must be cautious in drawing conclusions from the work of Hofstede, Rochlin, Roberts, and LaPorte. It is clear that several aspects of the national differences may have implications for safety and for efficient operation of NPPs. Obviously differences in the willingness of employees to follow rules, or to suggest innovations are important. It may be that in certain cultures, (those with high PDI and UAI scores,) it would be difficult to persuade the workforce to adopt the kind of flexibility and inventiveness that are advocated by Rasmussen and Vicente (Rasmussen, Pejtersen and Goodstein, 1995; Vicente, 1999). The extent of co-operative rather than individualistic competitive attitudes to one's fellow workers is also important. And several of the findings may be relevant to selection and training (Boegel et al., 1985). It would be interesting indeed to make a more extensive cross-cultural study in which Hofstede's scales are related to the degree of HRO achievement. Unfortunately it would be difficult to find a comparable workforce to study. There is no corporate entity concerned with NPP operation that has a global presence comparable to IBM, and indeed studies by the US NRC have pointed to substantial differences among utilities even within the USA. On the other hand, one might suggest that the similarities in the fundamental engineering characteristics of PWRs would be equivalent to commercial globalization by a company such as IBM, in which case a combination of the approaches of the Berkeley group and Hofstede would be possible. It would at least be suggestive.

Hofstede's study was performed in the early 1980's, and there have been substantial changes in the socio-economic structures of many of the countries he examined. The economic depression of the "Asian Tiger" economies and of Japan has changed the attitude to lifetime employment at least in the latter country. The advance of privatization of industry in the western industrial nations may well have changed the national characteristics, or at least the balance, of the ICI from that found by Hofstede. The differences in national characteristics may be less stable over time than they appear intuitively. Also, the suggestion by Hofstede that there are differences when occupations are examined compared with the examination of national characteristics is important. Commercial, government, and economic pressure for down-sizing and so-called "rationalization" of work forces in the interest of competitiveness and shareholder profits may mitigate against the kind of HRO found in the military setting by Rochlin, Roberts and LaPorte. But equally, as even military systems become international, studies like these will be increasingly important.

There is a clear implication that while in HROs there may be rigorous procedures and hierarchical command structures in theory, and by design, in practice these are used in a markedly informal and self-adaptive way. It is not likely that in the US context, the Nuclear Regulatory Commission would accept deviations from the official procedures on the scale described in the work on the aircraft carrier; nor is it plausible that such flexible arrangements would be acceptable to the public at large in NPPs. That is not to say that such changes would not be accepted should it be shown beyond doubt that by so doing the reliability of NPPs is increased, but it is unlikely that most, if any utilities would be allowed to adopt such strategies and tactics under the current regulatory regime.

Again, consider the self-reporting or errors with a ”blame free” attitude by management, or the idea of special groups or teams whose job it is to search actively for faults and signs of weakness in the system. This seems very plausible as a means of increasing reliability, but in the context of world-wide industrial practice it may be hard to implement. (Rochlin and van Meier (1994) report that even such a notion as a suggestion box was greeted with derision by French NPP personnel and by Greek workers, so that ideas which seem to some of us self-evidently worthwhile may not match the cultural stereotypes of social behavior, just as we saw that some ergonomics of control rooms do not match cultural stereotypes of perception-action coupling.) Currently there is a world-wide emphasis on down-sizing personnel in all industries under the impact of global competition and de-regulation of energy supplies. Few utilities would feel it acceptable to maintain extra personnel whose main job was to search for faults, when, by and large, there are few significant faults and no serious accidents. (This is, of course, despite the fact that were there to be another Chernobyl or even another Three Mile Island it might sound the final death-knell for the nuclear industry.)

Furthermore, consider the relation of the list of characteristics of HROs to ”national cultural characteristics” such as those investigated by Hofstede, and those cited by other sources. Is the picture drawn y the Berkeley group essentially an American picture? There are a number of commercial companies which provide briefings to Westerners intending to undertake commercial operations in Eastern countries. These briefings are based on generalizations about cultures outside North America and Western Europe, and are intended to teach people what to expect about how Eastern cultures do business. They are of course pictures filtered through a western psychology of business practice, but it is instructive nonetheless to look at the kind of things which are said. Here are some implications drawn from a document about doing business in Japan.

1 Elaborate mechanisms have been developed to prevent direct confrontation during discussions. In the face of a threat the initial response is to withdraw and meditate on the significance of the threat
2 Everyone is required to voice their opinion
3 There is a reluctance to come to a definitive conclusion
4 Decision-making in Japan is ”middle-up-and-down” unlike that in the USA which is ”top-down”.
5 Decision-making is by consensus, which leads to a general sense of participation by all those who take part, increases morale, enables rapid implementation once a decision is made,, and means that if there is failure, it is shred rather than individualized.
6 Typically much forethought and discussion, occupying a long period, precedes decisions.

Similarly, one finds characterizations of Russian business practice in a briefing prepared to support an exchange between American and Russian nuclear scientists:

1 Russians are risk-averse, Americans are risk-seeking.
2 Russians will not talk to a boss about a problem.
3 Russians do not show initiative because it will cause more work: in practice initiative gets punished.
4 Russians withhold information because knowledge is power; Americans share information.
5 Russians will not admit that they do not know the answer to a problem. Americans are encouraged to admit they do not know the answer.
6 Russians work around rules using personal contacts when they find the rules are insupportable.

The issue here is not that these pictures of cultural differences are completely accurate. Furthermore, these are not pictures of NPP personnel, but broad brush pictures of the culture as a whole, and in particular of how commercial business is conducted. But there must be *some* basis for such pictures. If such cultural differences exist, or if others exist which are equally different from one culture to another, what is their impact likely to be on the reliability of NPPs, and can the prescription for HROs drawn by the Berkeley group be filled in such cultures?

One possibility is, of course, that such differences are indeed present, but they do not have any impact on the ability of an industry to produce. That seems unlikely. Clearly the degree of readiness to take initiative, the readiness of individuals to admit error, the readiness of individuals to act rapidly and without discussing problems with others, and the readiness to re-organize the hierarchy of responsibility would make an enormous difference to the ability of an organization to be an HRO of the type found by the

Berkeley group. Even if such differences only apply to management rather than operators or engineers it would have a major impact. On the other hand, one may accept the suggestion of some organizational theorists that the technological task demands of a high technology hazardous industry are so powerful that anyone who works in such an industry is driven by the technological requirements rather than by his or her culture. Such a view maintains that the culture of an operator is the plant, not the nation. In that case there would be no problem in people moving from one operating culture to another, although it might be difficult for them to start up a consulting company in a different culture. But we do not know if that is true, and there are suggestions in the work of Bourrier (1999) and Rochlin and von Meier (1994) that it is not true.

Overall, it seems that there are certainly national, or at least cultural differences, at all levels of operation, ergonomics, organization, and management; and that at all of these levels there are substantial differences between different locations and organizations. It follows that when large, high technology, hazardous installations such as NPPs are exported, or designed by one country for another, there are important cultural aspects to include in the design process. Similarly, when international co-operation is attempted, either for the long term improvement of safety, such as in the case of the eastern European and ex-Soviet Union plants, or when short term intervention is performed to assist at times of crisis, it is important to understand the implications of cultural factors as well as ergonomic and engineering aspects of NPP operation.

Notes

1 Recently there seem to have been some changes in this acceptance following nuclear industry accidents in Japan.

2 In the earlier book IBM was called the “HERMES corporation”.

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CHAPTER FOUR
A Review of Six Human Reliability Assessment Issues for the UK Nuclear Power & Reprocessing Industries

BARRY KIRWAN AND KEITH REA

This paper[1] describes a review of six issues in applied Human Reliability Assessment (HRA). These issues have been raised by the Nuclear Installations Inspectorate, acting for the Health & Safety Commission, the body responsible for the UK Generic Nuclear Safety Research (GNSR) Programme for civil nuclear power generation, which includes a general item on HRA. As these HRA issues are common to nuclear chemical plant, the review was commissioned as a joint project involving civil nuclear power and reprocessing (NP&R) industries. The review's objective was to help prioritise these issues and determine ways forward for achieving practical tools and approaches. These issues were as follows:

1. *low probability events and human error probabilities;*
2. *modelling recovery;*
3. *cognitive errors and errors of commission;*
4. *dependence modelling;*
5. *the appropriate level of decomposition to use in HRA;*
6. *advanced/dynamic HRA.*

The paper outlines the issues themselves, and the concerns which led to those issues. Insights from the review process are explored, including those techniques seen as most promising research avenues or as best practice. Additionally, more generic insights are explored such as the role of context in HRA, the failure of mature second generation HRA techniques to appear, and a potential relationship between practically-oriented HRA and the achievement of a positive safety culture.

BACKGROUND

In the UK Nuclear Power and Reprocessing (NP&R) industry, Human Reliability Assessments (HRAs) are regularly carried out for nuclear installations, as part of a general programme of risk assessment on behalf of the licensees and the regulatory authorities. Such HRAs may be carried out for new designs or for existing installations, and they aim to determine the human contribution to risk for the installations, and often also to give insight into means of reducing error or improving error recovery. The general HRA approach has been in existence internationally for some time, but it is recognised that there remain certain problematic aspects of HRA. These do not necessarily prevent HRAs being carried out, but they may affect the accuracy and usefulness of the results achieved using conventional HRA techniques. There is therefore an ongoing programme of research and development in the UK to try to develop better and more effective methods of managing the human contribution to risk for nuclear installations.

Since the UK Nuclear Power and Reprocessing (NP&R) industries have many human reliability and Human Factors issues in common, a number of these can be addressed via joint research and development projects. Her Majesty's Nuclear Installations Inspectorate (NII), acting on behalf of the Health & Safety Executive, raises these issues, and the Industry Management Committee (IMC) commissions and manages projects to resolve the issues, and improve NP&R industry performance. Examples of raised and resolved issues are the validation of three HRA techniques (Kirwan et al, 1997a), and the development of a human error database (Kirwan et al, 1997b).

A number of Human Reliability issues, however, have remained unresolved for some time, due to other priorities for nuclear safety research and development. These issues are shown below:

1. **Quantification of low probability events**—i.e. how reliable are operators in very infrequent events?
2. **Modelling recovery actions in HRA**—i.e. how do we account for how good operators can be at recovering from their own, their colleagues', and the system's failures?
3. **Cognitive and commission errors**—what should we take account of in terms of misconception or misdiagnosis errors, or rare but bizarre operator actions that may threaten the integrity of the nuclear power safety systems?
4. **Human error dependency**—how should we account for increased failure likelihood due to the same operators or teams of operators doing related tasks during emergencies? What makes a good independent check, and what makes for a poor one?

5 **Error-based versus task-based approaches**—how detailed should our analyses of operator involvements be, when we are carrying out risk assessments?
6 **Advanced/dynamic human reliability modelling**—should we pursue (for analysis purposes) developing complex, interactive models which emulate the mind of the operator?

Since these issues had been raised but not yet addressed by the IMC work programme, there was a perceived need to examine whether they were still important and, if so, how they could be expedited. Clearly other work had taken place (in the UK or elsewhere) in the intervening time which could have resolved them either partly or completely. Additionally, it was possible that the need for some of the issues was less pressing now, or in fact could even have become redundant, although other issues were likely to be still seen as important, and in fact their perceived urgency may have actually increased. It was therefore necessary to establish how important these issues were, and whether any of them had been, or could now be, resolved, in order to develop a suitable way forward.

OBJECTIVES

The objectives of the work were therefore as follows:

(i) Review the relative importance of the issues, both from a UK and a more global perspective.
(ii) Determine whether any solutions to the issues now existed.
(iii) Determine, based on findings related to objectives (i) & (ii), how IMC should proceed with regard to expediting the issues.

SCOPE

The scope of the review was purely to review the issues, not to develop new approaches. It was also aimed at achieving ways forward for rapid resolution of these issues, rather than suggesting large-scale future long term work programmes. The review, as described below shortly, was also investigative rather than academic in nature in that as much, and potentially more, credence was given to what key personnel (including some academic practitioners) said, rather than to what the formal literature suggested. This was for three principal reasons. First, the best literature (journal articles) tends to be two years behind actual progress, due to extended review and publication cycles. Second, much published literature is often rather optimistic about the real practical usefulness of its proposed methods—what looks good in the laboratory may find a real nuclear power context too challenging. Third, many industry HRA personnel are generally aware of the literature, and if there were clearly useful solutions sitting somewhere in journals, they would probably already have been identified as such.

The review therefore, as described below, was highly pragmatic in its approach, and whilst it covered the relevant literature, and some useful new information arose from that source, the most insightful and decisive information without doubt came from interviews with key people.

APPROACH

The approach was in three main stages: interviews with the licensees and the regulatory authorities; further interviews and observations at the key HRA conference during the study timescale; and literature review. These are each briefly outlined below.

Licensee & regulator interviews

The first approach in determining what to do with these issues was to interview the licensees about them. Five in-depth interviews (conducted by the authors) were held with 2–3 key personnel from each organization. Each interview typically lasted half a day (usually a morning). The authors gave a preamble as to the reasons for the work, and clarified any issues relating to the project scope or the meaning of the issues themselves. The interviewees were asked to state any relevant work they knew of related to the issues that might resolve them, whether these were methods used now or under development. They were also asked the relative priorities (a ranking) of the issues, and at the end of the interview whether there were any other issues they felt also needed to be addressed and, if so, the priority of such new issues relative to the outstanding issues.

Attendance of PSAM IV conference

This conference, held in New York in September '98, although more generally a risk assessment conference, had special emphasis on contemporary HRA, via a large number of sessions devoted to HRA, and informal workshops reviewing where HRA should be going. It was also well-attended by international experts and practitioners, and the first author was able to interview many key leaders in the field of applied and theoretical HRA, and also key licensee/regulatory personnel, from the USA, Europe, and the Far East.

Literature review

Human Factors and safety literature (over 80 journals and associated conferences and published workshops) for the last three years (1996–1998) was scanned and 326 references were identified relating to human error and/or human reliability assessment or risk assessment. This search did not restrict itself to nuclear power, since HRA techniques from other industries were also of interest (in practice nuclear power remains the dominant domain for HRA publications, although medical applications are notably on the increase). This large set of references and associated abstracts was further reduced by the author to a set of approximately eighty references pertinent to the six issues. The literature analysis included various UK NP&R related reports, such as IMC Generic Nuclear Safety Research (GNSR) and Human Factors in Reliability Group (HFRG) reports.

RESULTS

This section summarises the principal conclusions from the three related approaches.

Issue 1: Low Probability Events

This issue comprises two aspects: human reliability during rare accident sequences, and very low human error probabilities (HEPs). The former links with the second issue of recovery, and was seen by the licensees as the more important aspect, whether from a HRA/PSA perspective or a station safety viewpoint. This was also seen as a significant issue elsewhere, although the literature yielded few significant ways forward.

The issue of how low HEPs can be, was not seen as so important, and the literature yielded very few papers dealing with this issue (e.g. Dougherty and Collins, 1996). However, the UK CORE-DATA (Computerised Operator Reliability and Error database, Taylor-Adams and Kirwan, 1995) project has developed a human error database which contains some well-founded very low probabilities (e.g. IE-4–IE-5). Given this resource, it was therefore recommended that such data be analysed to understand what factors lead to such high reliability and, perhaps more importantly, what factors limit human reliability to the more 'traditional' 1.0—IE-3 region.

Issue 2: Modeling Recovery

This issue was of particular concern, with respect to infrequent events, rather than with modelling recovery *per se,* which was seen as something of an academic issue that could be dealt with by consolidating best practice in the UK. Modelling recovery ties in with low probability events and, to a less important extent, level of decomposition (task versus error-based description —see 5.5 below). Two particular avenues were identified, namely the IMC's

DORRET approach (Determination of Operator Recovery Reliability over Extended Timescales), and another called 'INCORECT' (Investigating Cognitive and Recovery Tasks: Kontogiannis, 1997), which could be pursued. However, it is likely that new approaches will need to be developed. In particular, the approach that is needed is one which determines what happens in such events. For example, in infrequent events with long timescales, the emphasis has been on trying to quantify the extra benefit of such extended timescales. However, what may be more useful is the determination of what can be done, given such long timescales, that actually improves system reliability—this then would give more confidence in the higher reliabilities claimed, and would inform station operating practices when developing emergency procedures and contingency plans for 'beyond-design-basis' events.

Issue 3: Errors Of Commission (EOCs) & Cognitive Errors

This was seen internationally and from the literature (e.g. in the USA, see Dougherty, 1993, and in Europe—see Mosnerin-Dupin et al, 1997) as very high priority, if not the highest priority issue. Most emphasis is on mistakes rather than slip-based errors of commission (the latter are generally defended against by safety system redundancies and diverse protection). The solution requires two aspects: a tractable EOC/cognitive error identification approach, and a means of integrating the results into the Probabilistic Safety Analysis (PSA). There are ways forward in the literature, most notably the ATHEANA (A Technique for Human Error Analysis: Julius et al, 1996; Thompson et al. 1997) approach, although the earlier versions of ATHEANA are possibly more fruitful than the most recent incarnation of the method (see also Dougherty, 1998).

Also, the approach of dynamic event tree modelling (Gertman et al, 1996) suggested itself several times as a possible way forward for integrating the results of such analysis into PSA, and in one case it was shown that such modelling did not lead to the generally-feared exponential explosion of event sequences. The solution appears to lie in pragmatic HRA, with significant involvement of operating expertise, to cut out the irrelevant and even spurious EOCs (including cognitive errors) that may arise (e.g. see Kirwan et al, 1996). However, given the nature of EOCs and cognitive errors, the UK's pragmatic approach in this case does need to be backed up by more theory than is currently the case. Complex errors will not be identified or eradicated by simple approaches, nor by unadorned expert judgement.

Difficulties of quantification of EOCs, and of their inclusion in the PSA, should not preclude their analysis and the derivation of measures to protect against their occurrence. The real added value of EOC analysis is likely to reside in the qualitative rather than the quantitative analysis. Station operational involvement in EOC analysis could short-circuit the need for their inclusion in the quantified PSA, so that the EOC-focused HRA could produce directly useful station safety related information (namely credible EOCs and EOC defences). If EOCs are important but they are difficult to quantify and include in PSA, there are two options—ignore them, and have a PSA which has large residual uncertainties (due to non-inclusion of EOCs), or deal with them qualitatively and inform and improve station safety, and gain greater confidence in that safety. Although qualitative outputs and recommendations arising are difficult to prioritise, at least the station personnel will have been informed of the dangers, and can decide based on their own judgement how to prioritise them.

Issue 4: Dependence

Although understanding of dependence still has some way to go, and modelling of dependence is pragmatic rather than theoretically coherent, there appears to be enough known about dependence to model it satisfactorily. There have already been two large UK-based reviews of methods (Hollywell: 1996) and the nature of dependence (HFRG, 1998), so that further research in this area may be beyond the point of diminishing returns, given the pressing nature of other issues which are less well-understood or modelled. Some of the methods available for dealing with dependence are as follows (Hollywell, 1996):

- **usage of conditional probability data**—e.g. a check on another's work has a 'generic' HEP of 0.1
- **limiting value methods**—e.g. such that the maximum reliability of a team cannot exceed 0.9999
- **adjusted value methods**—adjusting HEPs according to amount of dependence of certain factors
- **scenario analysis**—considering scenarios in detail to understand how and why dependence might exist
- **fuzzy set theory**—use of this mathematical approach to quantify dependence
- **extended Boolean algebra**—using this advanced boolean mathematics to quantify dependence
- **simulation**—using fast-time Monte Carlo-based simulations to calculate the impact of dependence
- **multiple sequential failure method**—a method looking at the interactions of events
- **checklists**—which note factors likely to increase or decrease dependence

Although there are clearly a range of methods available, what does appear to need attention, however, is consistency of application of good practice. It was therefore recommended that a best practice guide for HRA practitioners be developed, to ensure that the good practice and range of methods available be used appropriately and consistently.

Issue 5:
Task Versus Error-Based Modelling

Very little research appears to be ongoing on this subject area (although see Kirwan, 1997), although it tends to be raised as an indirect issue in connection with other issues such as recovery, errors of commission, etc., and was a major concern of a few of the personnel interviewed. The problem is that trying to address this issue theoretically (i.e. what should be the appropriate level of decomposition for any HRA?) appears difficult, i.e. there is as yet no clear way forward on this issue. This issue essentially relates to determining the optimum level of resolution of an analysis, and it is difficult to optimise level of resolution without considering what the problem is. It was thought that this issue is therefore best embedded within another practical problem context, such as recovery in low frequency events. In such an application, a suitable level of decomposition will be found which yields the best information for analysing and optimising recovery. Whilst remaining a separately identifiable problem domain, it was considered appropriate that future work on this issue should therefore be subsumed within the new merged issue of ‘recovery in low probability events’.

Issue 6:
Advanced/Dynamic HRA

There is certainly a good deal of research in this area, including some sponsored by the USNRC, and a great deal of work ongoing in Korea and Japan, as well as some European initiatives (e.g. see Hasegawa and Yoshimura, 1996; Cacciabue, 1998; Kirwan, 1996; and Lee et al, 1997). The work divides into dynamic human reliability methods which can lead to more integrated PSAs and modelling of dynamic event sequences, and cognitive simulations which could inform conventional HRAs/PSAs or the more dynamic approaches being developed.

However, it is not clear, after over a decade of such research, that we are much closer to seeing any of these approaches used in a real PSA. Furthermore, there is a noticeable trend, with several of the later cognitive models being developed for design rather than assessment purposes. This may be because the large resources investment required to develop such models can only be justified by the models’ outputs informing key design decisions (e.g. how many operators are required; which VDU-based system to use in a new design of control room; etc.). This has implications for the UK NP&R industry, where design of new installations is not the order of the day. Cacciabue, who is himself very involved in these areas (both dynamic HRA/PSA and cognitive simulation), noted (personal communication, 1998) that they tend to become overly complex to use for HRA purposes, and may serve better to help inform design and operating practices, rather than HRA.

Therefore, given that the UK does not have the complexity of HRA analysis that needs dynamic HRA, nor is it currently designing new installations, and given the persistent failure of these approaches to reach useful maturity, it was recommended that the UK NP&R industry should retain a watching brief in this area. If at some stage in the future useful tools become available, or if the UK develops a pressing need, then more active involvement could occur.

Summary

In summary, the six original issues were reduced to two larger ones and two smaller ones. The two larger and more important issues ('error of commission analysis' and 'recovery in low probability events') are unlikely to be achieved within a short timescale. These two larger issues will require more significant effort, but should be able to build on key work ongoing elsewhere as reported in the literature. The two smaller ones, namely consolidation on 'human error dependence modelling' via a best practice guide, and investigation of 'very low HEPs' within CORE-DATA, are most probably achievable within a relatively short timescale. 'Task versus error-based modelling' could best be dealt with by it being subsumed within the above 'recovery in low probability events' issue, and the issue on 'advanced/dynamic human reliability modelling' should be to review, inform and retain a watching brief on this area.

DISCUSSION OF HRA, SAFETY CULTURE, AND CONTEXT

Context & 'Practical HRA'

On a more general note, the UK approach to NP&R contrasts with that of other countries, as being highly pragmatic. This is seen as advantageous. Although there is less theoretical development and underpinning in the UK, it is the practical nature of the work, and the operational input it utilises, that derives real insights into how to make UK nuclear power and reprocessing installations safer. There are thus tangible difference in the quality and utility of a HRA that has used significant operator input from the respective installation, and a HRA which is carried out remotely from the site and without reference to operational personnel. The main differences are the following:

- **Capturing the context**—as Dougherty (1993) noted with respect to HRA, 'context is everything'. This means that predicting what errors will occur and how often they will occur, depends entirely on the details of what the operator is trying to do and his/her understanding of the situation, and what factors are affecting performance in the scenario, i.e. the context.
- **More credible error modes**—capturing the context leads to more credible error modes, in that feasible but operationally-incredible error modes will be ruled out or quantified accordingly. Conversely, realistic and insightful error modes which are more likely, due to local factors and working practices, will be identified and included in the risk assessment. This means that rather than the HRA or risk assessment being a generic one for any plant of a particular reactor design, the HRA will be specific to that installation. The chances of identifying accident trajectories and recovery modes that are relevant to that installation are therefore far higher.
- **Operational face validity**—the operational relevance means that the plant operational personnel themselves will have more faith in the HRA/ risk assessment, and will see it as potentially insightful and helpful, and a credible test of their procedures and training etc., rather than just another management 'hoop' to jump through.
- **Better error reduction recommendations**—the higher face validity and focus on local operational context, will mean that operational personnel will become more involved in assisting with the identification and evaluation of recovery measures, in terms of whether they will be effective in practice as well as on paper.
- **More operational usage of resulting safety case information**—because the operational staff will be more likely to 'buy in' to the recommendations, because they have been involved in their specification and evaluation, the safety case itself is likely to inform station operating procedures and training and working practices. There is then a real chance for a safety case to become a living and operationally useful document for the station.

HRA and Safety Culture

The above more practical approach to HRA can be seen as addressing certain aspects of safety culture. Reason (1998) has recently suggested that above all, a safe culture is an informed culture, one with proper information and appreciation of all the risks facing an organization. There have been numerous HRAs that have been carried out over the years in a number of countries which will have been seen by the plant personnel as academic, and to have little actual relevance to the plant's operational lifetime. Such HRAs and their 'parent' risk assessments may end up simply sitting on shelves gathering dust. They may have been necessary to have made a decision on whether to allow a design or operational plant to continue, but they have been insufficient to actually inform the organization about the relative priority of human error-related risks facing the plant, or of new and safer ways of recovering from certain events. A HRA which is carried out 'closer' to the organization and operational personnel of the plant, which incorporates the operational context, will have several benefits. First, it will be more effective in identifying the right risks, i.e. those that really matter to the plant in question. Second, it will help in getting operational and management personnel to recognise (i.e. believe they are possible) and think about those risks. This is Reason's main point—that in a safe culture, people are thinking about safety. Third, it will help in generating ideas on how to prevent certain risks or provide contingencies for their occurrence. Therefore, more practical HRA can help an installation move towards a more informed and hence safer culture, and HRA would be seen to be adding safety value to an installation.

Furthermore, as Reason has also pointed out, in very safe industries such as nuclear power and aviation, most companies have so few incidents, that 'organizational complacency' can occur, wherein the organization will effectively not believe that the rare events will ever happen, and so will remain unprepared practically and psychologically to deal with such events if they do one day occur. HRA, by dealing with the context and creating a fairly detailed 'picture' of such rare event scenarios, makes such rare events seem less abstract, and therefore more credible. It may be that there is still a belief that they will not happen, but the organization may well be more likely to consider the contingencies and emergency planning and training for such events. As a result, they will be more practically prepared for the event should it happen.

Second Generation HRA, Context, and the Assessor

This paper could not end without mentioning so called 'second generation HRA techniques'. Dougherty first called for these some years ago (Dougherty, 1993), but few have arisen, with prototypical tools being those such as ATHEANA, CREAM (Hollnagel, 1998), and some of the cognitive simulations already mentioned. The aim of such techniques was to more properly model and represent the complexity and contextual and goal-driven nature of human actions and decision-making. However, few of these techniques have as yet met with significant success, and so are still under development—achieving the worthy goals of context-based HRA seems to be harder than envisaged.

However, what seems to have been missed in the literature is an alternative route to capturing context, via the assessor and the living context embodied in the operational staff of a nuclear plant's organization. An experienced assessor will be able to capture context and interpret it accordingly, and ensure the main human error and recovery contributions to the risk equation are appropriately captured. If the assessor interprets the operational context or culture inappropriately, then operational staff used as referent experts or for feedback, should be able to detect and correct this. Essentially, if capturing context is proving too difficult to embody reliably in a technique (as progress in developing HRA techniques is suggesting), then the risk/safety community should return to a tool that it knows can understand and interpret context and culture—the human. It may be that in the future better tools are developed that can achieve the goals of second generation HRA more effectively and with less vulnerability to assessor bias, but in the meantime those goals can still be achieved, albeit probably without optimal reliability.

Conclusion: towards a practical HRA culture

This paper has shown how a number of HRA issues have been analysed and prioritised. It has concluded that the issues of recovery in low probability events, and cognitive errors and errors of commission, are the two that should be prioritised for further work. Both of these issues will only be resolved by a focus on context, in terms of how cognitive errors and EOCs can occur as a function of the operator's mindset and other factors in the scenario, and in terms of the details of what must be done and with what resources in low probability serious events. They both require a more contextual approach than that traditionally used in HRA. This more contextual approach will probably affect the modelling (task analysis, error identification, and performance shaping factor identification) part of HRA more than the quantification part. Since no current techniques fulfil the needs in this area, it is likely that new approaches will be developed. These may not constitute new techniques as such, however, as instead they may simply amount to more attention to the context, more use of task analysis approaches, and more interfacing with operational personnel to gain information. This amounts to a much more practically-based HRA approach, one in which the assessor becomes embedded within the context and culture of the scenarios. The authors believe that this already occurs to an extent in UK NP&R assessments.

It is recommended that such a practical emphasis continues to be a dominant characteristic of UK NP&R HRA 'culture', and that more usage is made of operational input, especially in these potentially key future areas such as error of commission analysis and recovery modelling. This will lead to robust and realistic methods, and to the uptake of operationally-informed, valid and focused safety improvements. It will also enhance the credibility and utility of HRA itself within the industry. Such an approach, if implemented and effective, would better inform the industry of the key human-related hazards, and so would represent a very real step on the path to achieving a safer culture in the NP&R industry.

Notes

1 This paper describes research commissioned by the UK nuclear Industry Management Committee (IMC) as part of the Health & Safety Commission (H&SC) Co-ordinated Programme of Nuclear Safety Research. The views expressed are those of the authors and do not necessarily reflect the views of the IMC, the NII, the H&SC, or participating organizations.

2 The literature search was carried out by the Ergonomics Information Analysis Centre (EIAC) in the School of Manufacturing and Mechanical Engineering at the University of Birmingham, UK.

Acknowledgements & Disclaimer

The authors would like to acknowledge those personnel who participated in the various interviews in the UK and at PSAM IV. The opinions of this paper are however those of the authors, and represent their interpretations of the interviews and the literature, and so do not necessarily reflect those of the UK organizations involved in the study.

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PART TWO

Societal dynamics and trends in nuclear safety issues

Introduction

Specific studies of nuclear industry responses to socio-economic change are grouped together in Part Two.

Analyzing the Human Event Database of the Japanese nuclear industry, Monta describes the industry's attempt to increase popular credibility by identifying major research themes for further human factors research. Such major themes comprise Human Reliability Analysis, the improvement of databases, human-machine system environments, organizational factors and safety, and accident management approaches.

Using data from the USA as relevant for other countries as well, Meshkati, Butler, and Pelling study the potential safety consequences of the deregulation of electricity markets. Such consequences are seen to flow mainly from attempts by the nuclear industry to reduce variable costs in the three optional domains of fuel expenses, operating and maintenance costs, and capital additions.

Kitada, Ato, and Matsuda demonstrate the efficient Japanese use of public opinion polls for the continuous analysis of public response to the nuclear industry, particularly in reaction to major incidents or accidents. Each nuclear event that receives publicity can be shown to diminish the favorable popular evaluation of the industry's trustworthiness.

CHAPTER FIVE
The Significance of Safety Culture for Nuclear Power Operations

KAZUO MONTA

Safety culture is requisite in order to make the safety principle of "defense-in-depth" permeate into the actual design, construction, operation, and maintenance of nuclear power plants. In order to assess the significance of safety culture for nuclear power plant operations, a chart developed by a review committee on future human factors study has been adopted. Based on this chart, the relation between the safety culture and nuclear safety and accountability of safety policy could be examined through human reliability analysis, a human factors database, and organizational factors. Human behavior is highly dependent on the situational context. The development of a method for systematically examining this context is aimed at proactively challenging the incident, including human cognition in a broad sense. In order to draw lessons from the human error event database in Japan, factor analyses of these data were performed for data from 1981 to 1995. The participants in a discussion on organizational factors in PSA/PRA, which was based on a report on organizational factors related to nuclear power plant safety, have proposed the application of experimental methodology that uses a simulator for the assessment of safety culture significance.

One of the most important issues facing nuclear energy in Japan is improvement of its public acceptance, that is, the task of gaining the public's sense of ease toward and confidence in nuclear energy through its safety performance. Although the technical safety of nuclear energy remains important, the corresponding goal of winning society's confidence in nuclear energy activities is indispensable for Japan's energy security, environmental protection, and so on. Accountability for the people working in the nuclear energy industry and, hence, efforts to provide information to all members of the public should therefore be pursued at all levels and in every domain of nuclear energy activities (Murata & Kanda, 1998).

The International Atomic Energy Agency (IAEA) working group on shortcomings in safety management reported its conclusions at the 1998 IAEA conference on topical issues in nuclear, radiation, and radioactive waste safety. According to the authors of this report, “Experience has shown that once nuclear installation has deteriorated…then the magnitude and difficulty of the effort required to recover performance are such that continued viability of the organization comes into question. It is extremely important to be able to detect shortcomings and deterioration of safety management performance before it becomes a serious concern.” (IAEA, 1998). Indispensable for safety management, nuclear business acumen “is the insight, knowledge and ability to manage the unique interaction between the technology, economics, human factors and safety in a changing nuclear business environment. A review of the developing safety culture was a factor considered necessary to ensure sustainability.” (IAEA, 1998).

The first safety principle with regard to nuclear energy is “defence-in-depth.” The second safety principle, “safety culture,” is necessary in order to make the first permeate into the actual design, construction, operation, and maintenance of nuclear power plants (NPPs). In order for the safety and the economic competitiveness of nuclear energy to develop continuously, it is necessary for all people concerned to be made aware of the responsibility for each action and that the making of necessary judgments be transferred to the appropriate level of the organization.

Safety culture makes it possible for the intelligence of each person to be used for the achievement of the competing goals of safety and economic competitiveness while ensuring that the people concerned understand the observance of the orders coming from the top of the organization. At the same time, safety management that contains monitoring functions in all of the organizational levels will become increasingly important as the level of responsibility transferred increases.

In the dialogue with the public, one of the factors causing discontent appears to be the lack of openness toward the public about incident information. Incident information is by nature quite important for people working in nuclear energy activities because it contains important lessons to be learned. In order to promote this learning, an analysis of the root cause of the incident and the deployment of a countermeasure based on this analysis should be made. The information acquired through this process should be shared by all stakeholders, including the general public.

REVIEW OF THE HUMAN FACTOR STUDY

The human factor study of the nuclear energy industry has been systematically performed in Japan since 1987, following the Chernobyl accident. Since then, there have been significant changes with regard to nuclear energy, such as increased economic competition and increasingly serious public concerns about the safety of nuclear energy. Safety culture is one of the most important themes to be studied, for its study will enable the concept to be fully developed and utilized for the safety management of nuclear energy.

The Institute of Human Factors of the Nuclear Power Engineering Corporation (NUPEC), under the sponsorship of the Ministry of International Trade and Industry, undertook in 1998 a review of themes for future human factors research (Institute of Human Factors, 1999*a*). This review was performed by a committee consisting of experts from nuclear utilities, research and academic communities, and a regulatory body. After reviewing domestic and international activities in human factor research up to the present and forecasting future trends of research needs and seeds, the committee compiled a list of important future themes for human factor research (see Table 5.1).

The themes are categorized into five groups: human reliability analysis (HRA), the database, the human-machine system environment, organizational factors, and accident management. The committee also requested an evaluation of this list by an independent expert group.

Figure 5.1 shows the relationship of these themes as well as other factors, such as expected final outcomes, important infrastructures, and intermediate outcome and/or background factors.

As mentioned in the introduction, the accountability of nuclear safety policy and nuclear safety seems to be the leading objective for a discussion on the significance of safety culture in nuclear power operations. Hence, the themes of HRA, database development, and organizational factors (including safety culture) may be taken up as subjects that can assess the significance of safety culture in nuclear power operations. In the following, I review the current state of understanding of these themes as well as ongoing and planned investigations that take up these themes.

MAJOR THEMES AND THEIR IMPLICATIONS FOR SAFETY CULTURE

Human Reliability Analysis

One characteristic of human behavior is that it is highly dependent on the context of the situation or of the activities being performed. The shaping factors that influence performance must be well understood. In this regard, human behavior during the situation assessment process in risky situations, stressful conditions, or plant disturbance conditions is of particular interest. Knowledge of this behavior could help enable improved mastery of error mechanisms in such situations and help improve cognitive models for HRA (OECD/NEA Committee on the Safety of Nuclear Installations [OECD/NEA],

Table 5.1 Important Future Themes for Human Factor Research

Category	Examples of themes
HRA	Improvement of HRA method (second-generation HRA) Characteristics of error-forcing context Context dependency of unsafe actions HRA modeling of error-forcing context Performance-shaping factors for second-generation HRA Simulator validation of second-generation HRA (context dependency, shutdown/low power operation, new technology, organizational factors, etc.) Modeling of cognitive performance variation due to night shift Human reliability assessment method during maintenance Assessment method for organizational reliability
Database	Development of human factors database Database for operating experience and lessons learned Analysis and evaluation of operational experience
Human–machine system environment	Improvement of operational support Development and evaluation of advanced man–machine system technology Improvement of maintenance support Development of maintenance support system and maintenance work automation Improvement of maintenance tools through cognitive engineering Improvement of operational procedures and equipment maneuvering Improvement of work procedures through cognitive engineering Standardization of equipment maneuvering Assessment of workload and reliability correlation Assessment of operation and maintenance environment Control room environment Reliability of one-man operation Convenient assessment method for workload Effective color-coding method Systematic evaluation of operation and maintenance environment Systematic design evaluation of human–system interface
Organizational factors	Investigation of organizational factors and safety culture Effect of organizational change on member's motivation Teamwork and leadership for fieldwork Investigation of qualitative change of work force (aging, etc.) Advanced training for operation and maintenance (new technology, incident management, case-based learning about maintenance error, etc.)
Accident management	Emergency response Investigation of emergency response based on actual experiences Training on procedures for coping with unanticipated events

Note. HRA=Human reliability analysis.

1998). Indeed, as Colas (1997) pointed out, a reconsideration of whether human reliability goes back to the central theme of human characteristics and their effect on behavior in the work environment is necessary about this point in time in the nuclear energy industry.

At present, the development of the second-generation HRA model is being pursued in the United States (U.S. Nuclear Regulatory Commission, 1998) and France (Bieder, Le Bot, Desmares, Bonnet, & Cara, 1998). The developers of this model have adopted the hypothesis that the context of a complicated event in a plant transitory disturbance or accident leads a person to make an inappropriate judgement. Thus, the development of the method for systematically examining this context is aimed at proactively challenging the incident, including human cognition or human factors in a broad sense. The bases for this hypothesis are observation data from the event reports accumulated up to the present in the actual plant and from the records on simulator training.

This hypothesis may bring about a transformation of the traditional negative image of the "fallible human" into a paradigm that portrays the human being as actively contributing to safety. The hypothesis is also expected to enable analysis of part of the safety culture, because the effects of the safety culture on the context would then become the subject to study. Another expectation to be drawn from this hypothesis is that the desirable state of the safety culture can be conjectured, a point that is discussed in more detail in the section on organizational factors. If the transformation of this paradigm is realized, a change in the point of view about incident information will follow, that is, one can expect improvement of the process for explaining the causal context as well as improvement in the transparency of incident information.

In order to collect data that support the development of the second-generation HRA, the need for and use of additional simulator experiments should be taken into consideration (OECD/NEA, 1998). A simulator experiment project for the collection of data and the development and validation of a new HRA model has been performed in NUPEC since 1997. The project mainly comprises the development of experimental methodology (Institute of Human Factors, 1999*b*) and the corresponding experiments (Murata, Takahashi, Monta, Watanabe, & Komatsubara, 1999).

With regard to the development of experimental methodology, recommended methodologies for simulator experiments specifically tailored for the collection of data and of understandings about operator behavior in so-called error-forcing contexts (EFCs) have been proposed. The main focuses are (a) development of the framework and procedures for scenario design, (b) development of measures, and (c) development of basic guidelines for overall experimental design. Some preliminary EFC experiments on the latter focus have been performed; the former is still in the developmental stage. Hence, from now on, EFC experiments will be undertaken to

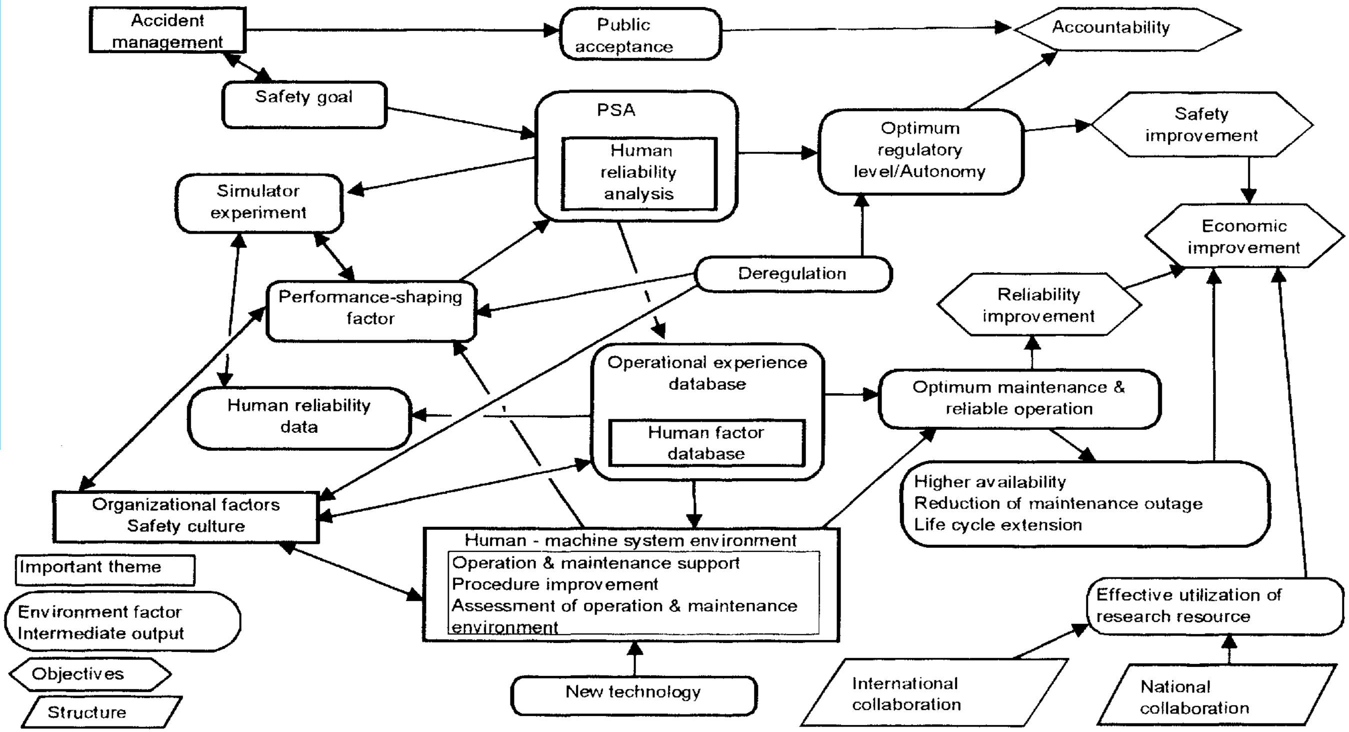

Figure 5.1 Realation between important human factor research themes and their objectives. From Jitsuyou genshiryoku hatsudensho hyu-man fakuta- kanren gijutsu kaihatsu nikansuru houkokusho. Annual Report on Human Factors Research Project, 1998 (p.590), by Institute of Human factors, Nuclear Power Engineering Corporation, 1999, Tokyo, Japan.

demonstrate EFC and to investigate erroneous human cognitive tendencies. The collection of these experimental data and the knowledge that can be attained through analyses of these data should be integrated into the operational event database (discussed in the next section) so that common EFCs, if any, can be identified; a more thorough investigation of common EFCs should

Human Factors Database Development

The Institute of Human Factors has been engaged in a project to collect, analyze, evaluate, and disseminate operational safety-related events in Japan in order to prevent both the recurrence of the same events and the occurrence of similar events (Hasegawa & Kameda, 1998).

Most events occurring in NPPs have a human factor contribution and should be analyzed from this point of view. Analysis of operational experiences of human errors is becoming internationally important for two reasons: The relative share of human impacts is increasing whereas technical impacts are decreasing, and events are manifesting human impacts that are not fully addressed in current HRA (e.g., commission errors).

The Institute of Human Factors has adopted an adapted version of Rasmussen's (1986) human error classification scheme. Based on an information-processing model of human performance, it provides a multifaceted classification scheme consisting of error modes, error mechanisms, and causes of error or situational factors that cause error. The classification scheme defines these elements as follows:

1 Error mode: human error forms are classified are classified according to a shared characteristic caused by an action or phenomenon that can be observed from outside. They can be divided into omission error and commission error.
2 Human error mechanism: this term describes the occurrence of human error through human internal cognitive information-processing in two ways: the first is the stage of cognitive information process (i.e., detection/identification, judgement/decision-making, action), and the second is the level of cognitive control (i.e., skill-, rule-, or knowledge-based level).
3 Causes of error or causal factors: this term is intended to describe the external factors that cause human errors. It is further divided into direct causes and indirect causes, where the former triggers the occurrence of human error and is called the initiating event and the latter is relevant to the way in which an error occurs and is called the influence factor. Based on experience and knowledge gained up to now and on the results of analysis and evaluation of events, causes of error occurrence are classified according to the following factors: the individual, the

> task, the task environment, the organizational and management factors. These factors make it possible to classify the initiating event and the influencing factor as latent root causes. Each factor has a subcategory with two hierarchical levels of its own. The higher subcategory for the organizational characteristic factor consists, among other things, of team structure or organization, inadequacies in instruction and supervision, and workshop morale. Education and training and regulation or work planning, among other things, form the higher subcategory of the management characteristic factor.

Based on the above classification scheme, a systematic chart of analysis and evaluation of human error events can be derived. Analysis sheets for human error events are then drawn up in order to extract the facts from the incident and failure reports that are submitted by utility companies.

An analysis was made of the human errors that occurred in NPPs in Japan from 1966 through 1995. Preventive measures against human-induced incidents and failures were also discussed. Of the 863 incidents and failures reported to the Ministry of International Trade and Industry from 1966 through 1995, 199 human error events were identified for 49 NPPs in Japan.

Figure 5.2 shows the causes of error for human error events. Because several causes may pertain to a single event, the total number of causes exceeds the total number of 199 human error events. Of the five characteristic factors, the management characteristic factor is second in the proportion of causes of human error events, and the organization characteristic factor is fifth.

In order to draw lessons from these event data, factor analyses of the human event data were performed for data from 1981 to 1995 (Yukimachi & Hasegawa, 1999). When differences due to the type of work are taken into account, it is found that maintenance error accounts for 55% of the total human error events and operation error accounts for 17%; these factors are treated separately.

Table 5.2 lists the major lessons to be gained from errors of operation and maintenance; the lessons relating to organizational and management characteristic factors are indicated in bold type. It can be seen from this list that almost the same lessons are drawn in almost the same order. This circumstance seems to indicate the importance of these lessons throughout the work process and, thus, how the reliability of NPP operation and maintenance can be improved directly from the organizational and management points of view.

Although the data used for the analysis span a long period (15 years) and include all plants in Japan, common characteristics seem to exist and to be obtainable through factor analysis. If additional minor incident data are available and increasingly detailed event analysis methodologies regarding, in particular, the organizational and management viewpoints, factor analysis seems to provide data for the assessment of organizational reliability for a certain period of time and a limited group of NPPs.

Recent advances in human event analysis provide detailed tools for the investigation of organizational issues (System Improvements, 1993). In addition, the international incident reporting system provides a broadened database with recently reinforced human factor descriptions (International Atomic Energy Agency & Nuclear Energy Agency, 1998). Further development of data accumulation, including data from simulator experiments, will be pursued. At the same time, improvement of event analysis methods with regard to recent advances in the analysis of organizational factors will be necessary in order to use the database to assess both the second-generation HRA and the contribution of organizational factors, especially of safety culture, to the HRA model.

Organizational Factors

A state-of-the-art report on organizational factors related to NPP safety was recently issued by the OECD/NEA Committee on the Safety of Nuclear Installations (1999). In this report, the following twelve factors are identified as important in the assessment of organizational safety: external influences, goals and strategies, management functions and overview, resource allocation, human resource management, training, coordination of work, organizational knowledge, proceduralization, organizational culture, organizational learning, and communication.

Of these factors, organizational culture includes safety culture and is defined as "refer[ring] to the shared assumptions, norms, values, attitudes and perceptions of the members of an organization" (OECD/NEA, 1999, p. 19). Safety culture, in turn, is defined as an aspect of the organizational culture in which safety is a critical factor in the norms, values, and attitudes of every employee throughout the organization. Some aspects of this factor include basic shared assumptions about how work must be performed in normal operations and in emergency situations, the safety awareness of individuals, and the reward and recognition system reinforcing safety work performance.

There is, however, no model or framework for these twelve factors that presents a picture of the interplay of different factors. The report indicates that one future need is to understand and assess the impact of organizational factors on human safety performance. In the discussion on organizational factors in Probabilistic Safety Assessment (PSA)/Probabilistic Risk Assessment (PRA), a claim by Erik Hollnagel is cited: "one should consider whether the basic approach of PRA should be revised, i.e., developing a PRA + ('PRA plus') approach. In the current understanding, all events take place in and are shaped by a context" (OECD/NEA, 1999, p. 26).

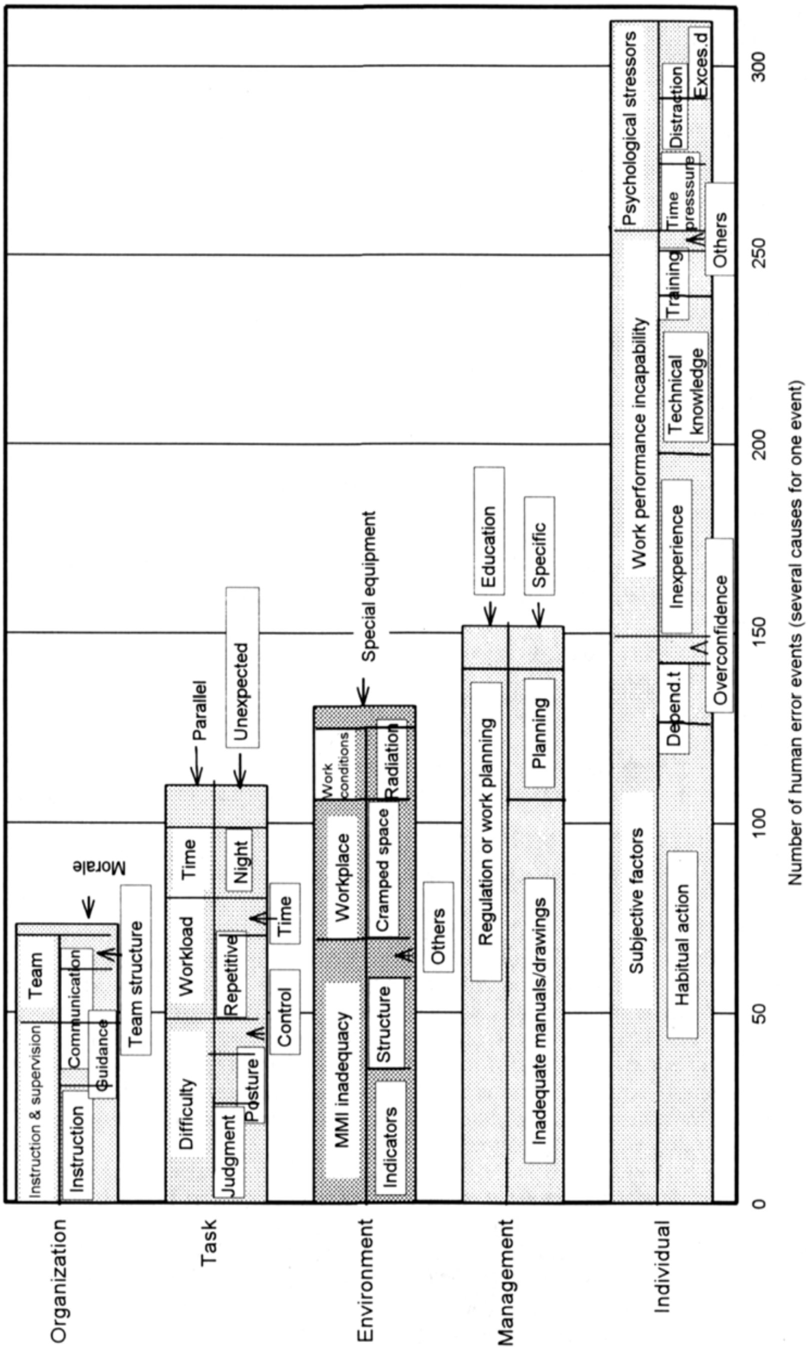

Figure 5.2 Causes of errors for human error events.

Table 5.2 Major Lessons from the Operational Event Database

Lessons from errors of operation	Lessons from errors of maintenance
Maintenance and improvement of integrated operational performance at work site	Maintenance and improvement of integrated performance beyond maintenance skills for individual equipment
Improvement of work environment management	**Refinement of work-schedule planning and management**
Improvement of communication and development of preventive measure against rigid mind-set	**Clarification of information and level of information detail necessary to work**
Reinforcement of and instruction in steady behavioral pattern	Development of precise discriminating ability for work
Prevention of simple speculative behavior and development of sensitivity and prudence toward unpredictable situations	**Reinforcement of equipment and parts provision and clarification of work orders**
Consciousness of danger at incomplete maturity	Measures for customization of conscious intention formation
Preventive measure against divergence or bias of attention	**Management for work-flow streamlining and for avoidance of temporary overwork, waste, and irregularity**
Promotion of less cognitively demanding work environment	**Removal or mitigation of bad conditions or difficulties in the work environment**

Note. Lessons relating to organizational and management characteristic factors are indicated

In the development of experimental methodology for simulator experiments (discussed in the preceding section on HRA), EFC coping factors have been introduced in order to account for the team skills that are expected to suppress the EFC and thereby reduce the chances that erroneous human cognitive tendencies manifest themselves.

The EFC coping factors in the team-skills dimension are information exchange, communication, supportive behavior, team initiative or leadership, task coordination, and adaptability. Through these factors the influence of the safety culture on PRA/PSA results, which is a measure of plant safety, can theoretically be derived, although further investigation of the influence of safety culture on these factors should be carried out, based, for instance, on the aspects of safety culture mentioned above.

Safety culture is based on "a rigorous and prudent approach" and "a questioning attitude" (IAEA, 1991, p. 13) at the level of the individual worker.

In order to realize these attributes, a deep, realistic understanding of the human being and the workplace (organization) characteristics is necessary. Bourrier (1999) has provided an interesting sociological analysis of scheduled outages of NPP, showing that organizational reliability is the result of a complex compromise between resource allocation and an actor's strategies within the organization. The exploitation of various methodologies, such as sociological and anthropological ones, is necessary, as is the accumulation of field studies based on such methodologies.

Features of the nuclear power management system of Japanese electric utilities were analyzed by Taniguchi (1997). The main instruments of the research were the questionnaire surveys and interviews given to the employees working at the department of nuclear power of the head offices, at nuclear power stations, and at the construction offices of three electric utilities. Taniguchi analyzed the structure of the nuclear power management system's framework and functioning from the points of view of organizational science and culture, and he identified the parts of the system with the universality and rationality to maintain parts of the system and the parts that are difficult or fragile to maintain under the changing environments surrounding nuclear power. One conclusion to follow from the research was the following:

The excellent safe operation of Japanese nuclear power plants in the last two decades may be said to be a result of the synergistic effect of the excessive response and adaptation to stringent societal pressures against nuclear power and the management system and the morale of the people concerned. The management system, which can be called a spontaneous and cooperative type, has been structured in an extremely ingenious way, centering the up-and-down behaviors of middle or senior managers. The core elements of the system emphasized from the viewpoint of a safety culture are teamwork, provision of motivations, information sharing, and organizational learning. (Taniguchi, 1997, p. 35)

With regard to the employees' attitudes and feelings toward and consciousness of their work, Taniguchi found that "differences or gaps can be observed significantly in some respects between elder and younger employees, although there is some commonness such a recognition that teamwork is very important for ensuring safety" (Taniguchi, 1997, p. 37).

The organizational issues that should be grappled with in order to further improve the total performance of NPP operations were then examined. In this respect, Taniguchi concluded:

In order to develop and strengthen the safety culture in the utility companies, especially power stations, the following should be examined.

- Implementation of a senior management program focused on acquiring basic knowledge of behavioral sciences and risk communication,
- Careful consideration to the respect of autonomy of the employee,

- Re-establishment of an organizational learning process
  - Development of the opportunity of essential learning, in particular for younger employees,
  - The activation of the argument and encouragement of questioning attitude by middle class managers,
  - Reconsideration of a consistent, comprehensive and continuous education system that includes the social safety, the plant safety from the working safety as well as on-the-job training,
- Clear indication of the safety goal as an organizational standard or value in the public place,
- Improvement of social understanding of nuclear power.

We should maintain our voluntary and cooperative type management system that has supported the nuclear energy industry in Japan from now on, too. Therefore, we should pay attention to a change in consciousness of the young organization member. A feeling of the in-sufficiency is seen as one tendency in the needs of the approval of the general public, and there is fear that the young member's needs do not move toward the more advanced needs of the self-actualization. (Taniguchi, 1997, p. 40)

CONCLUSION

In order to assess the significance of safety culture for the operation of NPPs, a chart developed by a review committee on future human factors study has been adopted. Based on this chart, the relation between the safety culture and NPP safety and accountability of safety policy could be determined through HRA, the human factor database, and the organizational factors. Safety culture is one aspect of organizational culture, which has been identified as one of twelve organizational factors by the Organisation for Economic Co-operation and Development/Nuclear Energy Agency task force on human factors.

In reviewing the current state of understanding of HRA, organizational factors, and database development, including research my colleagues and I have done at the Institute of Human Factors, one finds that human behavior, either that of individuals or of groups, is found to be highly dependent on the situational context or on the context of human activities. Thus, the focus of the problem is the relation between the safety culture and the particular context.

In HRA, especially the current second-generation HRA study, researchers studying the context of human error-forcing assume that the various performance-shaping factors couple with plant conditions, especially risky transient conditions that give rise to human error-forcing. The influential performance-shaping factors should be investigated in the light of recent knowledge on organizational factors.

In addition, the existing database on human factors shows the significance of organizational factors, and recent advances in the investigation of the root causes of an event focus on organizational factors. The facts that result from these efforts could provide valuable insights on the effect of organizational factors and safety culture on the performance-shaping factors and EFCs. The themes of HRA, organizational factors, and database development are therefore proposed as the main themes for the Institute's human factors study in the future.

Acknowledgement

Part of this paper was sponsored by the Ministry of International Trade and Industry of Japan. The author would like to thank all people who participated in those works. Thanks are also due to Dr. Taniguchi's group for their pioneering work in Japan.

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CHAPTER SIX
Nuclear Safety Culture and Electric Deregulation: Challenges and Potentials

NAJMEDIN MESHKATI, THOMAS S.BUTLER, AND KENDALL PELLING

Throughout the United States the movement to deregulate the electric power industry has become what appears to be an unstoppable wave; the electric utility industry is restructuring in response to federal legislation mandating deregulation. The potential economic gain from reduction of electricity costs is not, however, without potential monetary and nonmonetary risks to public health, safety, and the environment. This chapter presents the potential safety risks involved with the deregulation of the electric power industry in the United States and abroad. The pressures of a competitive environment on utilities with nuclear power plants in their portfolio to lower operation and maintenance (O&M) costs could squeeze them to resort to some risky cost-cutting measures. These include deferring maintenance, reducing training, downsizing staff, excessive reductions in refueling down time, and increasing the use of on-line maintenance. Many of these practices have already been documented within the nuclear industry. We conclude that it is, rather, a very critical public-policy and technical issue that should be addressed in an interdisciplinary, systems-oriented fashion by all stakeholders.

The elimination of bureaucratic rate regulation that is accompanied by a shift to market-centered systems in the power generation sector, termed deregulation, is a movement that is sweeping across the United States and the international community. This movement to deregulate the electric power industry in the United States has become what appears to be an unstoppable wave, as state after state enacts rate deregulation and restructuring legislation. Governments are pulling the plug on the monopolies held by huge investor-owned utilities, allowing competition in the hopes that improving economic efficiency will result in rate reductions for consumers and industrial users. The effects of deregulation go beyond simple energy economics.

Deregulation causes a radical reshaping of the economic pressures that come to bear on nuclear power plants and their fallible human operators.

The nuclear power industry faces great uncertainties as the regulatory system that has guaranteed a fair rate of return is dismantled. Many aging nuclear power plants in the American fleet are burdened by high O&M costs, costly repairs, and looming decommissioning costs. The result is that many nuclear plants have difficulty matching the low rates of competing generators using low-cost fossil fuels. The pressure of a competitive environment on utilities with nuclear plants in their portfolio to lower O&M costs while increasing availability can squeeze companies into resorting to some risky cost-cutting measures. These measures could include deferring maintenance, reducing training, downsizing staff, excessive reductions in refueling down time, and increasing the use of on-line maintenance. Many of these practices have already been documented within the nuclear industry.

The focused effort to be economically competitive can become the driving mind-set in power plant management. This situation can adversely affect safety culture, which has been shown to play a vital role in preventing accidents (International Atomic Energy Agency, 1991, 1992). Informed observers have contended that this is the most crucial hidden issue in the rush toward utility deregulation. The degradation of safety culture at a struggling power plant could have major consequences not only for residents downwind but also for the international industry, which is striving to regain acceptance as a safe and cost-effective method of electricity production.

When the economic pressures to be a low-cost producer are coupled with aging plants and poor management, the safety culture at a nuclear power plant could suffer from deregulation.

CRITICAL IMPORTANCE OF ELECTRIC DEREGULATION FOR NUCLEAR SAFETY AT NATIONAL AND INTERNATIONAL LEVELS

Two key organizations within the United States have recognized that the replacement of rate regulation with market forces will create economic pressures that may lead to unsafe practices at nuclear power plants. In 1997 Dr. Shirley Jackson, chairperson of the U.S. Nuclear Regulatory Commission (NRC), presented a strategic vision in response to deregulation, saying: “Our focus is on ensuring that, as the business environment changes, economic pressures do not erode nuclear safety.… Nuclear electric generators must continue to maintain high safety standards, with sufficient resources devoted to nuclear operations” (Jackson, 1997, p. 4). Twenty-two months later Dr. Jackson (1998b) presented findings that validated her earlier concerns:

> NRC safety assessments at some reactor facilities have identified deficiencies which may stem from the economic pressure on a licensee

> to be a low cost energy producer, which in turn may limit the resources available for corrective actions and plant maintenance, (p. 8)

During 1999, the U.S. General Accounting Office issued a report on nuclear regulation, stating: “Competition challenges the Nuclear Regulatory Commission to ensure that safety is not compromised by utilities’ cost-cutting measures, and that the decisions utilities make in response to economic considerations are not detrimental to public health and safety” (General Accounting Office [GAO], 1999, p. 2). Deregulation clearly raises significant concerns that warrant further investigation.

The movement to deregulate the electric power industry is not solely an American phenomenon, and unfortunately neither are the safety concerns that accompany it. Britain and the European Union have instituted competitive systems, and many other nations are taking steps toward similar actions. Surveying the movement toward deregulation, in the context of increased competition from fossil fuels, has led Dr. Mohamed El Baradei, director general of the International Atomic Energy Agency, to recognize a pressing need for more effective management of plant activities, such as outages and maintenance. Though he called for increased efficiency, Dr. El Baradei (1999) showed a strong concern about the possible effects of competition on safety:

> Continued vigilance is required by national regulatory authorities to ensure that there is no sacrifice of safety for the sake of profitability; that plant operators continue to devote the necessary resources to staffing, training, and maintenance; and that there is full adherence to operating procedures, (p. 5)

This challenge faces the international nuclear industry; we must watch for the increased risks that deregulation will bring and study those incidents where these risks are made manifest, so that we can strengthen mitigating forces. By doing so, we hope to ensure that the deregulated nuclear industry will not sacrifice safety in the frenetic rush for profitability.

SUBJECTING ELECTRIC GENERATION TO MARKET FORCES: ELECTRIC DEREGULATION

The electric utility industry in the United States has historically been divided into three functional sectors: generation, transmission, and distribution. These functions are carried out by approximately 3,500 entities in the United States, including investor-owned utilities, independent power producers, Federal Power Administrations, and publicly owned (municipal or state) utilities. There are entities that only generate electrical power; those which generate and transmit power; some, known as vertically integrated entities, which generate, transmit, and distribute power; and others that only distribute electrical power purchased from generators at wholesale. The majority of investor-owned utilities are vertically integrated, full-service organizations. This vertical integration, which precludes competition, was originally seen as a technical necessity of electric power distribution and labeled a "natural monopoly."

Since the 1920s price regulation has been implemented to ensure that the vertically integrated utilities would not take on the negative characteristics of a monopoly. This primarily has been accomplished by a regulatory body, such as a public utilities commission, in each state. The regulatory body sets retail electric rates in order to protect consumers from monopolistic price-gouging, while ensuring that utilities receive a fair rate of return on their investments. In addition, the transmission and wholesale rates of electrical energy in interstate commerce has been regulated by the Federal Energy Regulatory Commission. The poor economic efficiency of the price-setting system has fueled the deregulation movement.

The economic inefficiencies caused by price regulation are demonstrated by the stranded costs in the generation sector. These costs are primarily sunk costs in less economical power generation assets, such as some nuclear power plants. These plants were constructed by utilities and approved as "prudent investments" by regulators at the time of construction. The regulatory structures guaranteed utilities a specified rate of return. "In effect, the more a plant cost to build, the more money a utility could make. Nuclear plants were the ultimate expression of this insane principle" ("The Electricity Business," 1998, p. 63). The massive construction debt was intended to be recovered through the rates paid by the captive consumers. However, under the economic cost pressure of a competitive power generation sector, the obsolete plants will not be able to match the costs of technologically advanced generating systems, such as combined-cycle gas turbine using low-cost natural gas; investments in the obsolete plants are "stranded." According to several estimates, the stranded costs of electric utilities in the United States are in the range of $70 billion (Navarro, 1996, p. 112–115) to $100 billion (Joskow, 1997).

Deregulation seeks to replace regulatory price-setting with more efficient market forces. Extensive analysis indicates that competition between independent generating sources will force the marginal price for electricity to follow the marginal cost of production of electricity (Joskow & Schmalensee, 1983). Consumers are expected to recognize lower rates through this process. However, with the elimination of price regulation, the guaranteed return on investment which utilities have received would no longer be available, leaving utilities with the stranded costs mentioned above. Joskow (1997) recognized the importance of mitigating these costs in describing the challenge of deregulation:

> The key technical challenge is to expand decentralized competition in the supply of generation services in a way that preserves the operating and investment efficiencies that are associated with vertical and horizontal integration, while mitigating the significant costs that the institution of regulated monopoly has created.

This challenge has largely been faced. The Federal Energy Regulatory Commission, by means of Order 888 issued in May of 1996 and reaffirmed in November of 1997 (Jackson, 1998b), has endorsed the strategy of allowing "public utilities and transmitting utilities to seek recovery of legitimate, prudent and verifiable stranded costs." The State of California has taken such action through legislation (Assembly Bill 1890, September 1996) to provide investor-owned utilities the opportunity to recover all generation-related stranded costs in up to four years. In addition, the public utility commissions of many other states have taken action to allow the recovery of stranded investments in generation (Jackson, 1998b). Whereas the recovery of stranded costs has been both supported (Brennan & Boyd, 1997) and opposed by economists (Navarro, 1996), the political trend is becoming clear. The allowance of stranded cost recovery is becoming a common trait of actions to deregulate the industry. This success in obtaining regulatory and political approval may be attributed to the relative strength of the regulated community and the "economic" or "simple capture" theories of regulation (Upadhyaya, 1997).

The predicted cost savings are contingent on the establishment of a truly competitive market. As evidenced by the deficiencies seen in the deregulation of the electric power industry in the United Kingdom since March of 1990, structuring this market can be a difficult task. The effectiveness of the "British model" of deregulation has been questioned because, after implementation, a duopoly in the generation sector developed, which limited competition and led to the manipulation of prices (Green, 1996).

ECONOMY AND COMPETITIVENESS OF NUCLEAR ENERGY

Although nuclear energy provides an important share of the energy supply, it is threatened by a deregulated environment. Nuclear power is a major source of energy for the United States and the world, and it is second only to coal in the United States, generating over 20% of the national energy supply (Department of Energy, 1998, p. 5). Similarly, 16% of the world electrical energy supply is generated by the 434 nuclear power plants operating in 31 countries (El Baradei, 1999, p. 2). Some of these plants remain efficient and profitable, notably those that are newer facilities with larger capacities, whereas others, generally older facilities with smaller capacity, face significant challenges. In the deregulated environment many nuclear power plants have difficulty competing with other energy producers, even after the recovery of stranded costs have been guaranteed. Nuclear generation benefits from fuel costs, which are much lower than fossil fuels, but the costs of O&M, capital intensive repairs, and regulatory actions can make competitive prices difficult to achieve. In a deregulated environment, poorly competitive nuclear plants will be under great pressure to return a profit to investors. The danger is that some actions undertaken to improve the bottom line may compromise safety margins or degrade the broader safety culture of the organization.

Rothwell, who has written extensively on the economics of nuclear generation, described the recent closures of reactors, which he attributed to primarily "economic reasons," and depicted a model for determining the average variable expenses at a nuclear plant based on three costs: fuel expenses, operating and maintenance costs that include expenditures on labor and materials (O&M), and capital additions (Rothwell, 1998). Rothwell referred to Hewlett's determination of the approximate price of 3.5 cents per kWh of bulk power sales (Hewlett, 1992). Rothwell's model is simple in one respect: The nuclear power plant must be able to produce electricity with variable costs at or below 3.5 cents in order to be competitive, and the variable costs are quantified in only three categories. However, for plant management, the challenge to maintain variable costs below 3.5 cents is a fairly complex undertaking.

The difficulty of developing and maintaining the low variable costs necessary for competitive prices is demonstrated by the prevalence of early closure of nuclear power plants. In the last 10 years, 11 nuclear plants in the United States have closed, with years of service ranging from 10 years to 34 years (Biewald & White, 1999). "The reasons given for nuclear plant retirement decisions generally include poor forward operating economics, and recently electric industry deregulation has been noted as an increasingly important factor" (Biewald & White, 1999, p. 4). Early retirements are widely predicted to continue, although the number of such retirements are dependent on the market price of electricity and the operating costs at specific facilities. The World Energy Service estimated that 26 nuclear plants will have production costs higher than the projected market prices of electricity, and so will be vulnerable to premature shutdown (World Energy Service, 1998).

Pressures on Utility Managers in a Competitive Industry

The new competitive environment of electric generation will likely intensify the pressures on plant managers to demonstrate performance improvements. The most extreme pressures for improved profitability will likely fall on managers who are hired to turn around struggling nuclear plants. When managers enter struggling facilities, not only does their job rest on their results, their reputation and future career can be greatly affected by the possible success of the plant. With a successful turnaround comes recognition in the industry and the possibility of great financial rewards, both of which are powerful motivators. The fear is that a poor manager who ambitiously and recklessly attempts to make a marginal plant show a profit will break down the safety culture, resulting in an accident-prone environment.

The turnaround of the Palo Verde plant in Arizona is a positive example of the new economic pressures at work. Mr. Bill Stewart came to the underachieving plant in 1994 and is credited with turning the facility into an industry star (Muller, 1998). When he came on board, “Palo Verde was kind of semi in the ditch, both operationally and regulatory wise,” Stewart said, “and people were being lined up to be let go” (Muller, 1998, p. B1). The layoffs appeared to be an attempt to improve the bottom line in spite of trouble with the reactors and regulatory pressure from the NRC because of safety violations. Stewart ended the layoffs, reduced O&M costs by $97 million a year, and reduced down time, resulting in a drop of production costs from a high of 2.49 cents per kilowatt hour to 1.33 cents per kilowatt hour, which is quite competitive with other power generators (Muller, 1998). Safety improved as well, earning high ratings in the NRC assessments. One investigator noted, for example, that “Performance in the maintenance area continued to reflect a superior safety focus” (Nuclear Regulatory Commission [NRC], 1998a). The plant has also received two straight top rankings from the Institute of Nuclear Power Operators. Stewart has now reaped the rewards of his success by moving up to head the generation division of Arizona Public Service Co., which owns 29% of the Palo Verde plant (Muller, 1998). Ambitious managers will likely seek the same success that Stewart has achieved.

In contrast, the management at the Millstone plant in Connecticut, also striving to cut costs, caused their safety culture and maintenance to deteriorate to the point that the NRC forced the reactors to shut down in 1996 and did not allow them to restart until 1998 (Rabinovitz, 1998). At Millstone, employees who raised safety concerns faced bonus reductions and other reprisals, even to the point of being fired (Pooley, 1996; Rabinovitz, 1998). In contrast, employees who did not raise costly safety concerns were rewarded through the bonus program, which utility managers created. Though two of the three reactors at the Millstone plant are about 10 years older than the three reactors at Palo Verde, the most striking differences are the responses of management when under pressure to improve efficiency. Whereas one developed a strong safety culture while maintaining the facility well, the other disregarded safety culture and cut corners on maintenance.

Early Closure of Poorly Performing Plants Will Eliminate Some Safety Concerns

The need for capital infusions to aging plants, in the form of major repairs, is a definitive factor in causing the closure of nuclear plants. When Commonwealth Edison closed the two reactors in Zion, Illinois, it cited the economic pressures of deregulation. Underlying these pressures was the need for costly repairs (Feeder, 1998). “Safety and maintenance problems had led the reactors to be placed on the NRC watch list of troubled plants,” and each reactor had been idle for over 16 months (Feeder, 1998). These reactors closed in spite of the $8 billion bailout by the State of Illinois for the recovery of stranded costs (Wasserman, 1998). It has been estimated that some plants will need repairs costing $100 million to continue operations (Kerber, 1997). Major repair expenses to machinery such as steam generators can readily outweigh some successful reductions in O&M costs. For this reason many of the oldest and least efficient reactors will not demonstrate increased safety risks as they respond to the economic pressures of deregulation, early closure and decommissioning eliminates the safety concerns associated with operation.

The Greatest Potential Risks Are at “Marginal Plants”

The potential safety risk arising from the economic pressures of deregulation will likely be greatest at those plants which are currently marginal. Nuclear power plants vary in age, operational costs, and reliability, which will affect the ability of the plant to produce electricity at or below the market price. The American Nuclear Society (ANS) pointed out that many plants will have operating costs that are low enough to remain competitive (American Nuclear Society [ANS], 1999). However, “some high cost plants or those needing major capital expenditures will no longer be economic and will be shut down” (ANS, 1999, p. 4). For example, Rothwell’s assessment of the decisions to close the Yankee Rowe and Trojan plants concluded that the “plants were closed after their owners determined that the Net Present Value of continued operations was negative or nearly negative” (Rothwell, 1997). The NRC, however, is most concerned about “those marginal plants that might reduce expenditures in an effort to increase competitiveness” (NRC, 1998b, p. 3). Those plants which are deemed to have the potential for profitability will be under great pressure to take the necessary actions to return a profit, and thus escape early closure.

NUCLEAR UTILITIES' POTENTIAL RESPONSES TO THE PRESSURES OF DEREGULATION MAY INCREASE RISK

In corporate business the pressure for profitability is a powerful motivator. This pressure leads companies to make risky investments and undertake painfully extensive downsizing and restructuring campaigns. In the deregulated environment the same motivator comes to bear on utilities that own nuclear power plants, which have previously been sheltered by rate regulation. In the past, expenses for maintenance and regulatory compliance were easily passed on to consumers, so management did not feel a strong pressure to reduce these costs. Because market pricing of electricity does not allow for direct cost recovery, the responsibility for cost reduction falls firmly on plant management. When management responds inappropriately to these pressures, safety risks become evident.

Electric Deregulation's Specific Challenges for the Nuclear Safety Culture

Reducing O&M Costs

Of the three variable costs that Rothwell identified at nuclear plants, O&M costs have the greatest potential for control by plant management. It is also an expense area where expenditure deferment or reduction has the potential for increased risk at the plant. Reductions in O&M expenditures could lessen the effectiveness of safety systems or impede operator effectiveness in preventing accidents, especially if those cuts are excessive or poorly crafted. It may be tempting for plant management to rationalize that a layer or two of the redundant safety and control systems may be allowed to fall into disrepair. Also, operator actions may not be incorporated into a defense against accidents because reductions in staffing or training reduces the possibility of having a fully trained operator at the controls at the right time in order to prevent an accident from progressing from an initiating event to a core damage event. Perrow argued that a complex system, such as a nuclear plant, has the potential for simultaneous failures of independent subsystems that have a synergistic effect on the reactor that neither the designers nor the operators are aware of. This synergistic effect can catch operators unprepared and unable to correctly diagnose the system malfunctions before serious consequences occur (Perrow, 1984). This dire situation underscores the need for a strong focus on safety. Cost-cutting efforts, which are undertaken in the duress of financial losses, may not fully appreciate the complex functions that certain expenditures provide for. Reducing O&M costs to improve profitability is a strategy that should not be taken lightly, nor implemented haphazardly.

It should, however, be noted that reductions in O&M costs and plant safety are not mutually exclusive. In fact, the NRC "has not found a strong correlation between levels of O&M and capital additions expenditure, and measures of safety performance" (NRC, 1998b, p. 3). This is a recognition that reductions can be implemented responsibly, but the incentive to act irresponsibly should not be discounted. The regulatory committee went on to recognize that there are concerns when plants "reduce expenditures in an effort to increase competitiveness," citing that under deregulation "incentives to take shortcuts may increase" (NRC, 1998b, p. 3). The incentive to take shortcuts is a direct affront to a healthy safety culture. When cost reduction becomes the top priority, the organizational safety culture can be seriously degraded.

Deferring Maintenance

Struggling plants have demonstrated a dangerous tendency to defer maintenance. The NRC publication *Establishing and Maintaining a Safety Conscious Work Environment* includes "as evidence of an emerging adverse trend" the example of "cost-cutting measures at the expense of safety considerations" (Jackson, 1997, p. 4). Just one example of this is the forced closure of the Maine Yankee plant, which demonstrated a backlog 3,200 deferred maintenance problems, 100 of which had been classified as high priority problems for over a year (Union of Concerned Scientists [UCS], 1998). Dr. Jackson (1997) noted that the significant deficiencies discovered at Maine Yankee "stemmed from two closely related root causes" and further elaborated:

> The first was economic pressure to be a low-cost energy producer, which limited the resources available for corrective actions and plant improvements. The second was the lack of a questioning attitude—a major component of a safety culture—which resulted in a failure to identify and promptly correct problems arising in areas that management viewed, not always correctly, as having low safety significance.

The report of Maine Yankee's Cultural Assessment Team shows serious degradation of the plant's safety culture:

> The current economic and political environment is considered precarious, and Maine Yankee's survival is seen to be based on a formula of low cost and high production. There is an associated fear among many employees that highlighting any negative issue could endanger the plant's continued operation.… At Maine Yankee, the Team found an organization struggling with forces requiring

> unprecedented change. These include evolving performance standards as well as deregulation within the electric utility industry. (Bradford, Chouinard, Fallen, & Jeffries, 1996, p. 8–9)

This push for low costs and high production supplanted safety as the primary concern. This situation leads to the rapid degradation of safety culture.

Reduction of Training Costs

One of the areas of increased O&M costs at nuclear plants subsequent to the Three Mile Island incident was a dramatic increase in the training of operators and maintenance staff (David, Maude-Griffin, & Rothwell, 1996). Rate regulation allowed for the complete recovery of these costs, but the in the competitive environment utilities must cover these costs from electricity sales at the market price which makes no consideration for costs of production.

The burden of these costs give management an incentive to search for sections at a plant where resources are being wasted on excessive training or training is not conducted in an effective or economical manner. A needs assessment and review of training effectiveness may identify areas in the training function for cost reduction. If this assessment is properly administered, within the context of a strong safety culture, savings could be recognized without compromising safety. However, when plant managers are faced with powerful economic pressures to rapidly reduce costs, cuts in training may be implemented without proper study, becoming excessive and reducing training that is vital to operational safety.

Possible reductions in expenditures for training is one of the safety concerns that the NRC raised in its *Final Policy Statement on the Restructuring and Economic Deregulation of the Electric Utility Industry* (1997, 62 Fed. Reg., p. 44071). Since this policy statement, “the [NRC] inspection process has identified several manifestations of inappropriate responses to competitive pressures” at several plants (NRC, 1998b). One effect of inappropriate responses noted is “decreased performance in operator licensing and requalification programs” (NRC, 1998b). This performance indicator shows the dangerous results of some cost-cutting efforts. In some cases, cuts in training expenditures have clearly gone too far. These actions reduce the effectiveness of training programs which are intended to mitigate the risk of human error, a major cause of dangerous malfunctions.

Staff Reductions

Downsizing is a common response to deregulation. Northeast Utilities began a five-year downsizing effort in 1996 that was expected to cut its nuclear workforce of 3,000 by one-third (Pooley, 1996, p. 49). The third largest utility in California, the Los Angeles Department of Water and Power recently undertook a major downsizing effort to improve competitiveness in response to deregulation. This municipal utility utilized early retirement and voluntary separation programs which resulted in many cases of serious under-staffing and loss of expertise (Prengaman, 1998). The potential for the misadministration of workforce reductions is striking, but fortunately the ensuing safety risks were less pronounced because this utility does not operate any nuclear power plants.

Concerns have been raised that utilities that operate nuclear power plants may quickly resort to downsizing to strengthen the bottom line when they are in financial crisis. The NRC Advisory Committee on Nuclear Safeguards raised concerns about the safety implications of workforce downsizing in a report to congress dated February 21, 1997. These concerns are reiterated in the commission's final policy statement (NRC, 1997). The methods used to reduce the plant workforce can also pose risks. The Union of Concerned Scientists raised the possibility that utilities will cut workforce costs by downsizing through early retirement and voluntary separation programs (UCS, 1998). They fear that these programs targeting senior employees who receive high compensation could lower the corporate experience level, thus increasing the frequency of human error at nuclear plants (UCS, 1998). While staff reductions in certain situations can likely be accomplished without compromising safety, other attempts to reduce personnel costs may have dangerous consequences.

Shortening Refueling Outages

As part of the effort to maximize availability, nuclear power plants are striving to reduce the amount of time which a reactor must be shut down for refueling. At the July 1995 Electric Utility Conference, Mr. Nat Woodson, president of the Westinghouse energy systems business unit, in his presentation "Gold at our Feet: Turning Around Nuclear Costs," stated that the industry is now seeking to bring the average refueling outage down to 24 days (Gunter, 1997). Although these reductions do not necessarily result in increased risk, careless attempts to reduce refueling time could.

The NRC cited the Millstone 1 nuclear power plant for carelessly performing full core fuel off-loads without allowing the proper cool-down time and without following other necessary procedures to mitigate the risks of a meltdown (NRC, 1999b). With each violation, Millstone accepted a significant risk of a meltdown of multiple cores in the spent fuel pool, in the case of a primary cooling system failure. The plant routinely ignored the 250-hour cool-down period, sometimes moving the fuel just 65 hours after shutdown (Pooley, 1996). This work process melted the rubber gloves and boots of workers assigned to the task (Pooley, 1996). Northeast Utilities, the owner of Millstone, reaped great financial savings from this practice: "By sidestepping the safety requirements, Millstone saved about two weeks of downtime for each refueling—during which Northeast Utilities (Millstone's owner) has to pay $500,000 a day for replacement power" (Pooley, 1996, p. 48).

When competitive pressures are coupled with the incentive of great financial savings, the temptation to shorten refueling downtime will be intense. It is a possibility that a plant which is in short term financial trouble would dangerously shorten a refueling outage to show a short-term increase in revenue.

Increasing On-Line Maintenance

The trend toward increasing on-line maintenance to reduce maintenance outage times could lead to increased risk. The NRC stated concerns about the safety risks of on-line maintenance in its *Final Policy Statement on the Restructuring and Economic Deregulation of the Electrical Industry, (62 Fed. Reg. 44071;8/19/97)*. The NRC has acted upon its concerns by formulating regulations for this practice. These concerns arise because this practice requires temporarily disabling one or more safety systems. On-line maintenance can help managers realize increased revenues, but regulated safety margins limit its use. Cognizant of the substantial financial gains associated with increasing availability, less scrupulous managers may rely on on-line maintenance for too many procedures, ignoring regulated limits and encroaching upon safety margins.

REACTIONS OF SAFETY REGULATORS AND THE U.S. NUCLEAR REGULATORY COMMISSION TO ELECTRIC DEREGULATION

Nuclear power plant operators have often complained that some NRC regulations cause substantial expenses but do not have a significant impact on safety. This criticism has intensified as operators begin to face the pressure to be a low-cost energy producer in response to the competitive deregulated industry. Many of the regulatory burdens were instituted in the aftermath of Three Mile Island accident, which initiated a major analysis of the safety of nuclear power plants and the potential for catastrophic accidents (Perrow, 1984). The NRC took action, instituting extensive regulatory requirements and required existing plants to be retrofitted with additional safety systems. Under regulated pricing, based on a fair rate of return on investment and full recovery of costs, these costs did not affect the profitability of nuclear plants. The costs of complying with the increased NRC regulations have been described by Rothwell and Rust (1998) as resulting in higher costs of electricity from nuclear plants. The U.S. General Accounting Office pointed out that, "In a competitive environment, utilities will not always be able to pass the costs of regulatory compliance on to consumers" (GAO, 1999, p. 16). As nuclear plants attempt to compete with low-cost producers in the deregulated environment, profitability will be affected by these costs. The efficiency of current regulatory burdens are now being reevaluated.

The NRC has recognized the legitimacy of the operator concerns and supports the idea that "a risk informed approach would reduce unnecessary regulatory burdens on utilities and their costs, without reducing safety" (GAO, 1999, p. 16). Acting on this idea, the NRC has recently initiated an new reactor inspection and oversight program which could have a significant impact on the nuclear industry in the United States. This new program is in response to "improvements in reactor safety over the last twenty years, the desire to apply more objective, timely, and safety significant criteria in assessing performance, as well as the agency's need to effectively regulate the industry with a smaller staff and budget" (NRC, 1999a). It is too early to assess the effectiveness of this new "risk-informed, performance-based" regulatory regimen. In light of the significant safety concerns associated with deregulation, and the pressures on the NRC to reduce the burden of regulation to keep plants operating, the effectiveness of NRC regulation should be the focus of continued study.

Deregulation has placed political pressures on the NRC to keep plants running so that the utilities can accrue funds to cover large decommissioning costs. Otherwise, these costs could become a liability of the public. In the past, however, the NRC has favored the industry and turned a blind eye to plant violations, most notably at the Millstone plant (Pooley, 1996). The safety of nuclear power plants would be uncertain if the NRC practices ease up on enforcement.

DISCUSSION AND CONCLUSION

Generating energy by burning nonrenewable fossil fuels including oil, gas, and coal is feasible only for the relatively short future, and, even so, it faces serious environmental problems. According to several credible sources, any serious study of the limitations of renewable sources (solar, wind, biomass, and hydro) shows that these cannot meet future energy needs, even backed by conservation. In the long run we have no alternative but to rely increasingly on clean atomic energy. We must continue to work on improving the safety of nuclear plants and the storage and disposal of their spent fuel. As fossil fuel power plants and other industries emit large amounts of carbon dioxide, they contribute to the so-called greenhouse warming effect on our planet, causing grave environmental concern, as noted in the Kyoto protocol. Nuclear power plants, on the other hand, do not have such emissions. Furthermore, research and development of advanced technologies for recycling carbon dioxide anticipate creation of an energy-intensive technology, which in turn and in the long term, use more electricity and increase the need for safe and clean nuclear energy.

A unique characteristic of nuclear power plants is that a large amount of potentially hazardous material is concentrated in single sites under the control of a few operators. The effects of human and organizational errors in these facilities are often neither observable nor reversible; therefore, error recovery is either too late or impossible. Lessons of Three Mile Island have had significant impact on the training and operation of nuclear plants in the United States. Operator training is now supported by 80 simulators (compared to 8 at the time of Three Mile Island accident), and procedures are now "symptom"-driven rather than "event"-oriented. These changes have contributed to decreases in the average number of automatic shutdowns from seven per year to less than one per year, and capacity factors have improved from around 60% to 80% (*Nuclear News,* March 1999). Nevertheless, the safety of complex technological systems—like nuclear power plants—is analogous to the stability of a three-legged stool: It is a function of cooperation and coordination among equipment manufacturers (reactor manufacturers), operators (utility companies and the trade unions), and regulatory and safety agencies (the NRC). In other words, the degree and smoothness of interactions among these key players determine the overall safety and economics of the nuclear power plants.

For the foreseeable future, nuclear power plants represent a substantial source of electrical energy in the United States. When analyzing the feasibility and effectiveness of various electricity generation options in the United States, there should be a systematic, logical approach toward nuclear energy, including plants' operating license extensions. Whereas facts and technological realities determine the role of nuclear energy in other industrialized countries, such as France, which relies on its 57 reactors for 83% of its electricity, in the United States this role is mired in emotional and ideological fantasies. "Antinuclear political correctness," using today's energy economics data and oil prices for tomorrow's strategic planning of energy generation, and flatly ruling out all forms of nuclear reactors, is not in the best long-term interest of the American people (or, for that matter, citizens of any other energy-thirsty country) and will undermine and stifle the prospects of secure and reliable energy generation in the future.

Restructuring of the electric power industry is an attempt to increase efficiency through the introduction of competition to the regulated markets in many countries. The most enthusiastic supporters of the deregulation experiment are careful to point out that the initial gains in efficiency are limited to the generating sector of the industry where competition is possible due to diversification and divestiture of ownership of the generating power plants. It remains to be seen whether the net economic and social benefit to society will be positive. The experience in other countries suggests that efficiency is increased overall, but that the average residential customer sees little or none of the gain. Perhaps society will see the net benefit in the long run by the more efficient use of resources in the generating sector. There appears to be ample evidence that the regulatory schemes for electricity generation pricing have not been able to benefit either the public or society.

Significant questions of survival, competitiveness, and safety surround the fate of the nuclear power industry under restructuring and deregulation. Several authors refer to the nuclear power plants as an experiment in progress. Some describe restructuring as an experiment, too. Still others suggest that the potential exists for the nuclear power industry to develop new plants that will be safer as well as free from the production of greenhouse gasses (unlike fossil-fuel thermal plants), leading to a significant nuclear power generating sector in the future. As suggested by NRC chairman Jackson, safety questions, including grid reliability and the potential for station blackout conditions, must be addressed (Jackson, 1998a). In any event, the nuclear plants must be able to compete economically while performing in a manner that convinces the public of their ability to operate safely.

If the cost of electric power is reduced by more efficient production through deregulation of the generating sector, then one would assume that the consumption of electricity would increase per the economic price-demand relationship for goods and services; as the price of a good or service is lowered, demand increases. One of the difficulties with increased consumption of electrical energy is the production of combustion by-products of fossil fuels. However, if more efficient power plants replace existing power plants, which currently produce more pollution per kWh, then the environmental degradation may not be as severe. It appears that the short-term fuel of choice for the United States and the United Kingdom is natural gas using the new combined-cycle gas turbine technology.

The final results of the restructuring of the electric power industry in response to deregulation will not be known for some time. One of the preliminary results is the initial decision to pass the stranded costs of inefficient plants on to the ratepayers in the form of transition charges. Several economists have argued against the ratepayers paying off the stranded costs because it delays the time until the marginal costs of power equal the marginal revenue. The investor-owned utilities so far have the political influence, and perhaps a strong legal argument based upon their assertions of regulator-approved expenditures for nuclear power plants and other facilities, to prevail for reimbursement of stranded costs at both the federal and state levels of government.

Perrow warned about "normal" accidents or system accidents at interactively complex and tightly coupled high-risk systems such as nuclear power plants (1984). Perrow also cautioned about complex interactions of systems that neither the designers or the operators are aware of and prepared to control. The complexity of nuclear power plants and their high reliance on the grid for power to prevent station blackouts under certain scenarios has raised questions at the NRC (Jackson, 1998a; NRC, 1997). This is another indication of why Perin (1998) has categorically characterized nuclear power plants as each being a unique experiment in progress. Joskow (1997) expressed concern about the potential for performance-based regulation to provide incentives for lowering the quality of service and about the apparent lack of thought regarding regulatory mechanisms over the newly emerging independent system operators of the electric power system.

Our research has found extensive examination of the electrical power system's elements and the potential effects of deregulation, according to research by particular academic disciplines. However, Rasmussen (1997a) questioned whether risks associated with systems such as the electric power system, which is undergoing fast-paced technological, economic, and regulatory change, can be adequately investigated using models based upon structural decomposition. He suggested that risk management should use a multidisciplinary approach and models based upon functional abstraction. In a recent analysis of regulatory decision-making, Rasmussen (1997b) contended:

> Commission reports from investigation of several accidents such as Bhopal, Flixborough, Zeebrugge, and Chernobyl clearly demonstrate that they have not been caused by a combination of independent failures and human errors, but by a systematic migration of organizational behavior toward accident under the influence of pressure for cost-effectiveness in an aggressive, competitive environment [italics added]. In this situation, decision-making at all levels of the socio-technical system (which are involved in the control of a hazardous process) must be reconsidered, including the efforts of the society to control the performance of operators, organizations, and companies by legislation, (p. 19)

In the United States, deregulation has dramatically changed the pressures which come to bear on the managers of nuclear power plants. This movement has shifted the nuclear power industry from a tightly regulated monopoly that nearly guaranteed financial returns to a competitive environment that gives few guarantees. The pressure for cost-effectiveness, and the corresponding threat of closure, is a powerful motivator that is capable of dramatically altering the organizational culture of a nuclear power plant. The managerial response to this powerful pressure has the capability of breaking down safety culture. When cost reduction replaces safety as the top priority of a plant manager, the safety culture of the power plant is seriously at risk.

When the pressures arising from the deregulated industry are placed on aging and marginally efficient reactors, the safety risks may be multiplied.

The pressure for cost reduction provides an incentive to defer maintenance at a point in the reactor's service life where the need to perform expensive maintenance is increasing. Strong safety-focused leadership is necessary to withstand the significant temptations to cut corners to reap profits. Effective regulatory oversight is necessary to identify those organizations that are willing to take unacceptable risks in pursuit of profit before another accident damages the nuclear industry.

Nuclear energy can be a safe and profitable generation method in a deregulated industry, but this situation will not come easily. Each state that endeavors to bring competition into the generation sector should be wary of the risks that the new pressures bring. National regulatory bodies continue to hold a primary role in monitoring safety. However, just as the effects of nuclear accidents transcend borders and jurisdictions, so do the necessary efforts to prevent accidents. The international nuclear industry should be vigilant about remaining focused on safety, creating incentives for safe operation that may help mitigate incentives for profitability. Safety should be the industry's most important performance measure, with economic performance a distant second.

Unlike the telephone, trucking, and airline industries, the potential effects of electric deregulation reach far beyond simple energy economics. It is in the nuclear field that the prospects of deregulation are most disturbing. In addition, it appears that the deregulation of the electric power system in the United States is an extraordinarily complex dynamic experiment encompassing multilevel economical, political, regulatory, social, organizational, and national security issues, as well as safety, health, and environmental risks of electrical power system operation and the specific risks associated with nuclear power plants. Furthermore, the future of the nuclear energy in the world is hinged on achieving economic viability while maintaining safety.

Thus, we conclude that energy provision is too serious a matter to entrust solely to bureaucrats, economists, and profiteers, when dealing with public policy issues affecting national safety, energy security, and diversity of supply. It is, rather, a very critical public-policy and technical issue that should be addressed in an interdisciplinary, systems-oriented fashion by all stakeholders.

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CHAPTER SEVEN
The Public's View of Safety Culture in Nuclear Power Stations

ATSUKO KITADA, KAZUNORI ATO, AND TOSHIHIRO MATSUDA

Adopting the point of view that the creation of a safety culture could affect the public's image of organizations in charge of operating nuclear power stations, we reconsidered the importance of safety culture by analyzing data obtained through public opinion surveys. The surveys conducted by the Institute of Nuclear Safety System have clearly shown that the public's perceptions of organizations operating nuclear power stations are closely related to their opinions on the use of nuclear power generation. The survey results demonstrated that the JCO accident resulted in an increase in the number of individuals who held a bad image of organizations operating nuclear power stations. These results suggest that efforts to create a safety culture would help establish an image of these organizations as giving safety first priority and create the groundwork for the public's acceptance of nuclear power generation.

Many industrial countries use nuclear power generation to meet part or most of their energy needs. However, nuclear power stations are facilities that carry a risk of inflicting serious damage on the residents and environment around them. Therefore, in order to use nuclear power, it is important that the public trusts that the operational safety of power stations is ensured. It is difficult to continue the use of nuclear power without public acceptance.

Many chapters in this volume reiterate the importance of building a safety culture among those working in the field of nuclear power, including nuclear power station insiders and regulators, in order to secure a high level of safety. In this chapter, we take up a viewpoint that is situated outside nuclear power stations and those working in them, namely, the viewpoint of the public. Using attitude survey data, we discuss the importance of whether or not the public perceives a nuclear power station as having established a safety culture. Needless to say, we do not presume that the general public accurately understands the concept of safety culture and thereby can make judgments about its presence or absence. The object of our study is whether or not the general public holds an image of nuclear power station management and employees that corresponds to an organization that must give safety first priority. For example, if the general public believes that the management of a power station conceals information on its failures from the public, this image would not correspond to an organization that must give safety first priority. Conversely, if the public perceives management as thinking about safety, this image would correspond to an organization that maintains its safety culture.

Even if the general public has never heard the words “safety culture,” it is aware that the safety of a nuclear power station depends to a great degree on the capability and soundness of the organization operating the station. For example, there is awareness that if an organization liable to neglect the observance and checking of safety procedures took charge of power station operations, this organization would bring on the cause of an accident in the power station.

Unfortunately, it is feared that three accidents that occurred in recent years have caused such awareness of issues to grow. The three accidents are the sodium leakage accident that occurred in 1995 on the fast breeder reactor Monju, which was operated by the Power Reactor and Nuclear Fuel Development Corporation (hereafter referred to as “Donen”); the fire and explosion accident that occurred in the Tokai asphalt solidification facility in 1997; and the criticality accident that occurred in JCO Company’s Tokai plant in 1999. What drew the attention of the public most was the fact that the operators who caused these accidents showed, both directly and indirectly, characteristics typical of an organization that cannot be trusted with operations involving nuclear facilities. Revelations about inadequacies in handling information on the accidents and in responding to society at the time of the accident forced Donen to be reorganized and JCO to suspend operations.

We have two specific objectives in this chapter: first, to use awareness survey data to confirm the relationship between the public acceptance essential to continued use of a nuclear power station and the image of the organization operating a nuclear power station and, second, to consider how the three accidents affected public opinion on the use of nuclear power generation. In pursuing these objectives, we first present brief accounts of the accidents in order to provide the reader with the background to the awareness survey. The awareness survey method is then described, and, finally, the awareness survey data are discussed.

SUMMARIES OF THE ACCIDENTS

The Monju Accident

On December 8, 1995, 0.7 tons of sodium used as secondary coolant leaked from the prototype fast breeder reactor Monju installed at Donen, located in Tsuruga City, Fukui Prefecture, causing a fire and damage to floors. The following sequence of events caused the leakage accident: A thermometer attached to the pipe through which the secondary coolant flowed was broken through high-cycle metal fatigue, which ensued from an engineering design error, and as a result a hole was made in the pipe where the thermometer had been attached. The release of radioactive substances to the surrounding environment through this accident was very small, with no personnel exposed to radiation.

The way Donen behaved after the accident raised questions, which were extensively covered by the mass media. First, Donen delayed in notifying Tsuruga City and the government about the accident. Second, it was revealed later that the videotape of the scene of the accident released by Donen had been edited to cut out footage containing vivid images of the situation and that a videotape different from the released one existed. Donen's attitude was severely criticized by the public, ultimately leading to a reshuffling of top Donen officials.

Donen, a government-owned corporation, had carried out the development of the fast breeder reactor. The accident report issued by the government stated that the accident severely damaged the nation's trust not only in Donen but also in the government's nuclear energy policies. With this accident acting as a trigger, the Atomic Energy Commission created the Round Table Conference on Atomic Energy Policy in order to better reflect the nation's opinions. As of April 2000, the prospects for resuming operation of the fast breeder reactor Monju were nil.

Accident in an Asphalt Solidification Facility

On March 11, 1997, a fire and explosion accident occurred at a Donen reprocessing facility located in Tokai Village, Ibaragi Prefecture. The asphalt solidification facility where the accident occurred was used to evaporate the water content of radioactive waste liquid produced during reprocessing in order to reduce the volume and mix the residue with asphalt for stable solidification.

The exposure of workers to radiation due to this accident was slight, with the release of radioactive substances to the surrounding environment in a small enough quantity that it would not affect health. However, the investigation performed after the accident revealed both the inadequacy of Donen's estimation of aspects of accidents and the insufficiency of Donen's disaster prevention facilities. In addition, it was disclosed that the accident report submitted to the government by Donen contained a false report giving an untrue time of confirmation of fire extinction. These revelations made it clear that the lesson to be gained from the Monju accident had not been learned, leading to criticism of Donen and its supervisory authority, the Science and Technology Agency.

A series of scandals and accidents, including the Monju accident, fire, and explosion and subsequent accidents, made it necessary to drastically reorganize Donen in terms of its internal characteristics, organization, and systems. In October 1998, Donen was reformed into a new organization, the Japan Nuclear Cycle Development Institution, with part of its operations curtailed.

Criticality Accident at JCO Company

On September 30, 1999, a criticality accident occurred at JCO, a privately owned uranium processing facility located in Tokai Village, Ibaragi Prefecture. It was the first criticality accident in Japan. The criticality state occurred because a large quantity of uranium, exceeding the prescribed quantity, was poured into a device not used in the normal work process. The criticality state was slow in coming to an end. A request for evacuation was issued to the residents within 350 m of the processing facility 4 hours 30 minutes after the occurrence of the accident. Later, about 300,000 residents within a radius of 10 km of the processing facility were requested to remain indoors. After 19 hours, JCO personnel broke the circulating water pump in order to finally stop the criticality state. According to the International Evaluation Scale, the accident was classified as a Level 4.

The release of radioactive substances to the surrounding environment due to this accident was slight. However, three persons engaged in the processing work were exposed to a great amount of radiation exceeding the lethal dose, causing two of them to die. It was established that 150 persons, including JCO personnel, those involved in disaster prevention work, and paramedics, were exposed. In the future, the radiation dose that the neighborhood residents were exposed to will be evaluated.

The direct cause of this accident was JCO's negligent control system: The company operated its processes not according to the regular work procedure approved by the government but rather according to a secret manual different from the regular one. In addition, employee training was insufficient and failed to make employees aware of the danger of a criticality accident.

This criticality accident led to the cancellation of JCO's business permit. In addition, Sumitomo Metal Mining Co., Ltd., the parent company and 100% owner of JCO, is expected to pay damages amounting to about 14 billion yen in compensation for agricultural damages due to bad rumors as well as damages due to forced absence from work.

Table 7.1 Surveys Conducted by the Institute of Nuclear Safety Systems, Inc.

Type of survey	Survey conducted in	Sampling method	Area	# of samples	% of returned answers
First regular survey	January 1993	Stratified two-stage sampling method	Kansai	1,500	75.9
Survey conducted two months after the Monju accident	February 1996	Stratified two-stage sampling method	Kansai	750	74.9
Survey conducted two months after the asphalt solidification facility accident	May 1997	Stratified two-stage sampling method	Kansai	750	71.1
			Kanto	750	68.1
		1993 survey respondents	Kansai	1,138	61.0
Second regular survey	July 1998	Stratified two-stage sampling method	Nation-wide	3,000	70.1
			Kansai	1,500	70.3
Survey conducted two months after the JCO accident	December 1999	Stratified two-stage sampling method	Kansai	750	70.9
			Kanto	750	70.1
		1998 survey respondents	Kansai	1,054	61.1

SURVEY METHOD

The awareness survey data used in this study have been obtained through a series of surveys conducted among the general public in Japan. Since 1993, the Institute of Nuclear Safety Systems, Inc. has regularly surveyed for public awareness of nuclear power generation. As a result, the institute has created a survey system that enables it to track changes over time in public awareness. When a major accident occurs in a nuclear facility, the institute measures the impact of the accident on public awareness by conducting a supplementary spot survey immediately after the accident.

Thus far, the institute has conducted two regular surveys for fixed-point observation of the public opinion trend in nuclear power generation and three spot surveys to measure the impact of major accidents just after their occurrence (see Table 7.1). The surveys were conducted by distributing questionnaires to people 18 to 79 years of age. For important questions, the

Table 7.2 Main Questionnaire Items Used for This Study

Question	Survey	conducted	in		
Anxiety about accidents in nuclear facilities	January 1993	February 1996	May 1997	July 1998	December 1999
Opinions on the use of nuclear power generation	January 1993	February 1996	May 1997	July 1998	December 1999
Images of workers in nuclear power stations				July 1998	December 1999
Images of nuclear power station management				July 1998	December 1999
Approaches taken by an electric utility that one can sympathize with				July 1998	December 1999
Degree of sense of security engendered through explanation of how safety is secured				July 1998	December 1999

same ones are used each time so that comparisons over time can be made. For a spot survey conducted two months after an accident, however, a simplified questionnaire with fewer questions than those contained in a regular survey is used. The survey questions used for the analysis presented in this chapter are listed in Table 7.2.

PUBLIC IMAGE OF NUCLEAR POWER STATION OPERATORS

Relationship Between Image of Nuclear Power Station Operators and Opinions on the Use of Nuclear Power Generation

It was first examined whether there is a relationship between the image of senior managers and workers in a nuclear power station and the opinion on use of nuclear power generation. Short sentences describing concrete images were presented in the questionnaires, and respondents were asked to check all the associations they made with the "senior managers of a nuclear power station and the workers working at a nuclear power station."

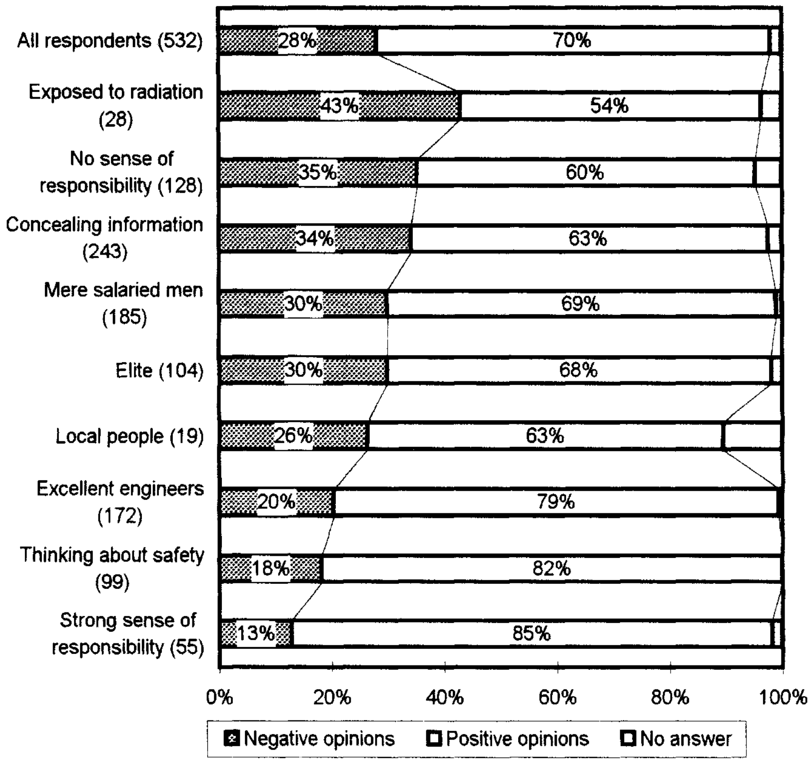

Figure 7.1 Images of nuclear power station management and opinions on the use of nuclear power generation

Figure 7.1 shows the ratios of pros and cons for the use of nuclear power generation by group that has selected a particular image of nuclear power station management. The figures in parentheses in the graph show the number of respondents who selected that particular image. The groups that see nuclear power station management as having a "strong sense of responsibility," "thinking about safety," and being "excellent engineers" have more opinions supporting the use of nuclear power generation than the average value for the respondents. Conversely, the groups that see nuclear power station management as being "exposed to radiation," "concealing information," and having "no sense of responsibility" have more objections than the average value for the respondents.

We believe that images of nuclear power station management as having a "strong sense of responsibility," "thinking about safety," and being "excellent engineers" reflect the image of an organization that one can trust with the operation of a nuclear power station. When a respondent associates

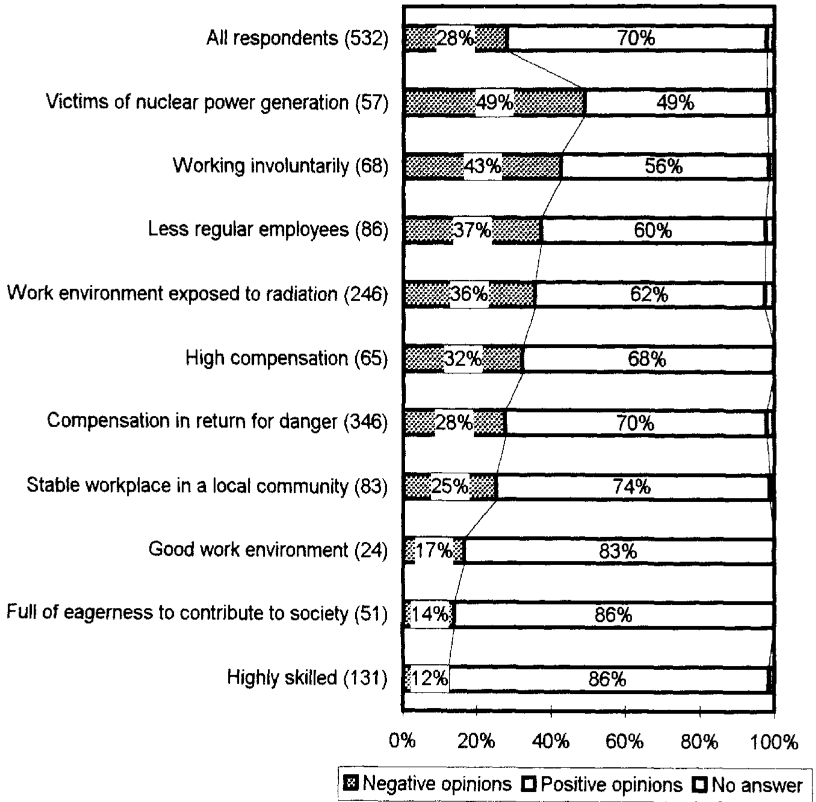

Figure 7.2 Images of nuclear power station workers and opinions on the use of nuclear power generation

these images with nuclear power station management, his or her opinion of the use of nuclear power generation tends to be positive.

Conversely, we believe that images of nuclear power station management as having "no sense of responsibility" and "concealing information" reflect the image of an organization that one cannot trust with the operation of a nuclear power station. When a respondent associates these images with nuclear power station management, his or her opinion of the use of nuclear power generation tends to be negative.

Figure 7.2 shows the ratios of pros and cons for the use of nuclear power generation by group that has selected a particular image of nuclear power station workers. The groups that see nuclear power station workers as "victims of nuclear power generation," as "working involuntarily," and as "less regular employees" have more negative opinions on the use of nuclear power generation than the average value for the respondents. Conversely, the

Table 7.3 Explanations of How Safety Is Secured in a Nuclear Power Station

Micro radiation around the power station is always measured and controlled.
Preventive measures against accidents, including fail-safe systems, are taken.
The defense that prevents radiation from leaking in case of a failure is adopted in the facilities.
When there is a sign of an imminent accident, the operation is stopped immediately.
Power generation facilities are built robustly enough not to be destroyed by natural disasters.
Every effort is made to prevent an accident from occurring.

groups that see nuclear power station workers as "highly skilled," "full of eagerness to contribute to society," and in a "good work environment" have opinions favorable to the use of nuclear power generation. In other words, when one believes that nuclear power station employees work in poor work environments and that their morale is low, one tends to oppose the use of nuclear power generation. Conversely, when one believes that nuclear power station employees work in good work environments and that their morale and technical skills are high, one tends to favor the use of nuclear power generation.

Image of Management as Concealing Information and Sense of Security Engendered Through Explanation of Safety

We next focused on the image of management as "concealing information," analyzing the effect of this image on the degree of sense of security generated through an explanation of how safety is secured in a nuclear power station. Table 7.3 lists six types of explanations provided in the survey sheet of how safety is ensured in a nuclear power station. Respondents were requested to read these explanations and answer as to whether such explanations give them a sense of security about the safety of a nuclear power station.

Table 7.4 shows the results. For each of the six types of explanations, the share responding that they do not have a sense of security depends on whether or not the respondents see management as concealing information. For the groups who perceive management as concealing information, the share answering that they do not have a sense of security is higher by about 20 to 30% than for groups that do not hold such an image. In other words, the image of a nuclear power station as a closed organization that conceals information negatively affects an individual's sense of security toward a nuclear power station.

The images that people associate with management and the work force in a nuclear power station may be regarded as reflecting the images that people have of the organization operating a nuclear power station. The survey data show the correlation between these images and the opinions held on the use of nuclear power generation. In a broader sense, the image of an organization can be seen as one of the elements making up an attitude toward nuclear power generation. It can be said that if an organization operating nuclear power generation does not give first priority to safety, and if it is seen as unenthusiastic and irresponsible, the safety of such an organization cannot be trusted.

CHANGES OVER TIME IN OPINIONS ON NUCLEAR POWER GENERATION

This section shows how opinions on the utilization of nuclear power generation have changed over time because of the three accidents that occurred since 1993 and considers the extent of the accidents' impact. To determine how public awareness has changed, two analytical methods were used. In the first method, the distributions for answers to individual questions were compared in time series. In the second method, composite indices (hereafter referred to as the overall attitude index) of answers to several questions were created for comparison in time series.

In carrying out a comparison, we used data that were obtained in the Kansai area through the stratified two-stage sampling method. In verifying the difference between the ratios of answers, we used empirical values that can be obtained on the assumption that the variance of errors in the stratified two-stage sampling is about two times the variance of errors in the unrestricted random sampling. Using these empirical values, we determined whether or not the difference at the 5% level was significant.

Anxiety About Accidents

We requested respondents to express their degree of anxiety about nuclear facility accidents on a four-stage scale: "very anxious," "considerably anxious," "a little anxious," and "not anxious at all." The change over time is shown in Figure 7.3. In all five surveys conducted, the total number of those who felt "very anxious" or "considerably anxious" exceeded one half the number of respondents, reaching high levels. The percentage of those who felt "very anxious" exhibited a statistically significant increase after the Monju accident. In 1998, this group tended to decrease in size. However, statistically significant growth has been observed since the JCO accident.

Table 7.4 Effect of Image of Management as Concealing Information on Respondents' Sense of Security About Nuclear Power Stations

		Explanation of micro radiation	
		% of respondents who are assured	% of respondents who are not assured
Image of power station management	Not concealing information	52	32
	Concealing information	37	56
		Explanation of the fail-safe system, etc.	
		% of respondents who are assured	% of respondents who are not assured
Image of power station management	Not concealing information	52	32
	Concealing information	31	62
		Explanation of the defense-in-depth system	
		% of respondents who are assured	% of respondents who are not assured
Image of power station management	Not concealing information	43	42
	Concealing information	26	70
		Explanation of safety being secured because of immediate plant shutdown	
		% of respondents who are assured	% of respondents who are not assured
Image of power station management	Not concealing information	47	39
	Concealing information	30	66
		Explanation of a nuclear power station being built robustly	
		% of respondents who are assured	% of respondents who are not assured
Image of power station management	Not concealing information	40	42
	Concealing information	26	66
		Explanation of company making every effort so that safety is ensured	
		% of respondents who are assured	% of respondents who are not assured
Image of power station management	Not concealing information	40	44
	Concealing information	23	70

Note. Adding the percentages of respondents who answered "he or she cannot say yes or no" to the percentages of respondents answering affirmatively or negatively comes to a total of 100%.

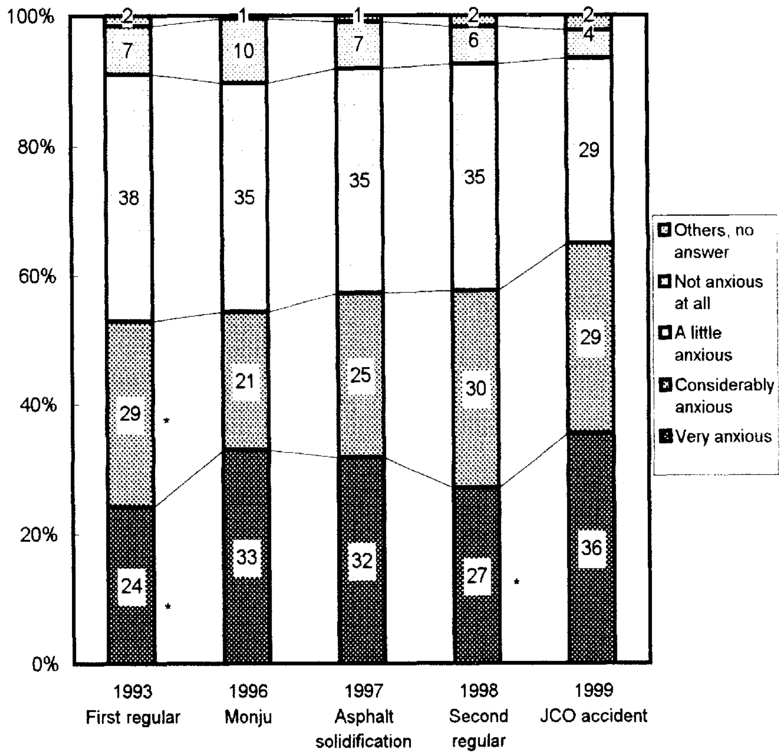

Figure 7.3 Anxiety about nuclear facility accidents. An asterisk (*) indicates statistical significance

Opinions on the Use of Nuclear Power Generation

Figure 7.4 shows the changes over time in opinions on the use of nuclear power generation. The respondent was asked to choose from one of the following options: (a) "Nuclear power generation should be used, though it requires considerations of safety"; (b) "using nuclear power generation is unavoidable, though some anxiety about safety remains"; (c) "safer power generation means that nuclear power should be relied on regardless of the cost and possible environmental destruction"; and (d) "nuclear power generation should not be used even if taking this stance makes life inconvenient."

After the Monju reactor and asphalt solidification facility accidents, the percentage of positive opinions declined. In 1998, however, an increase in the opinion that "using nuclear power generation is unavoidable" and a decrease in the opinion that "nuclear power generation should not be used" became significant, showing a positive tendency toward the use of nuclear power generation. Although the percentage of respondents giving the

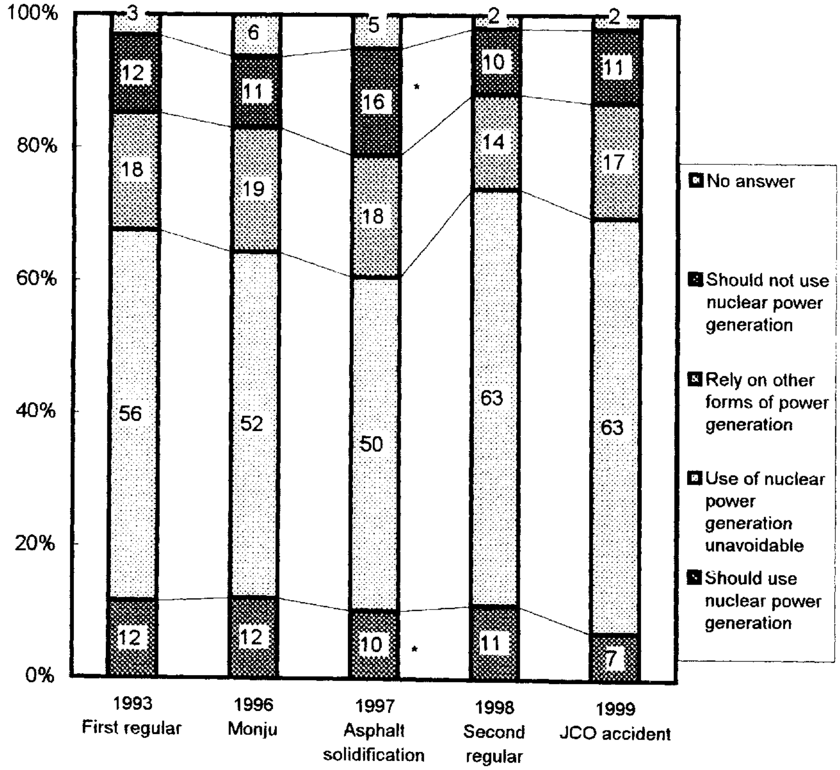

Figure 7.4 Opinions on the use of nuclear power generation. An asterisk (*) indicates statistical significance.

positive opinion that "nuclear power generation should be used" has decreased slightly since the JCO accident, no statistically significant difference has been observed for any of the options.

Overall Attitude Toward Nuclear Power Generation

Figure 7.5 shows the changes over time in the overall attitude indices. The attitude indices were calculated through the following procedure. First, we used data directly associated with nuclear power generation (see Table 7.5) from the survey data collected in 1993 and 1998. Using these sample data as variables, we performed quantification method III. Figure 7.6 shows the option score for Axis 1 and Axis 2 obtained through quantification method III. In the figure, options are distributed in a U-shape in the order of the degree of support for nuclear power generation, from options favoring it to those against it. Axis 1 can be interpreted as expressing the direction and intensity of approval or disapproval of nuclear power generation. Based on this interpretation, we defined the scores for respondents calculated using

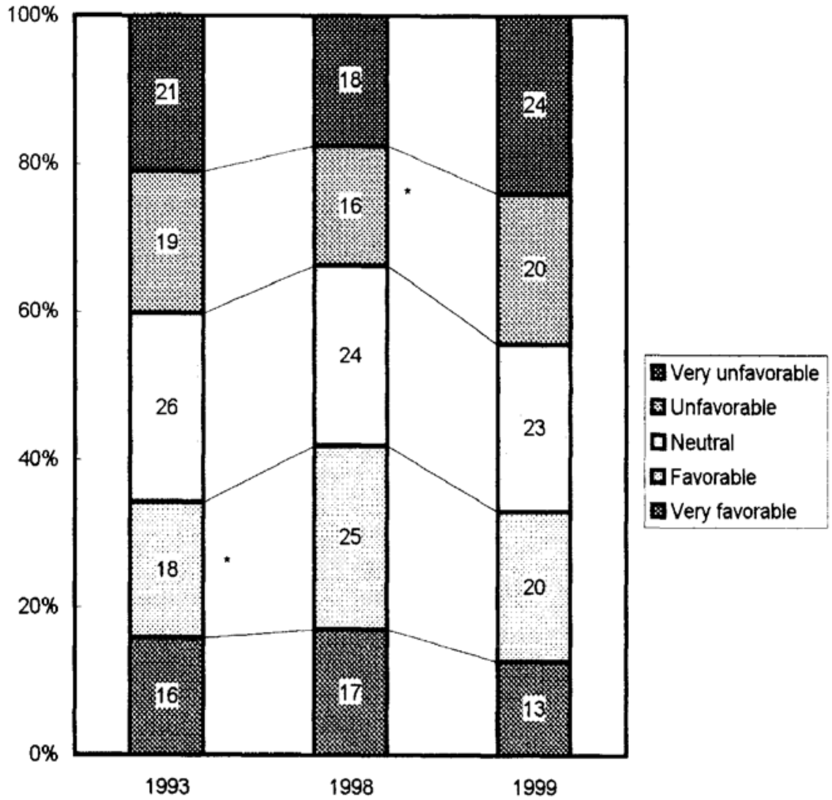

Figure 7.5 Comparison of attitudes to nuclear power generation through use of indices. An asterisk (*) indicates statistical significance.

Axis 1 scores given to each option as the overall indices of attitude toward nuclear power generation.

We have presented the respondent score distribution in a bar graph (see Figure 7.7). The negative scores represent responses in favor of nuclear power generation. Using this distribution, we classified respondents' attitudes to nuclear power generation into five categories. We sectioned the score value distribution at the values indicated by the arrows, classifying the values into five categories beginning from the left: "very favorable," "favorable," "neutral," "unfavorable," and "very unfavorable." Use of the sectioning score values as references to classify the respondents' attitudes not only allows the response data for 1993 and 1998 to be compared; it also allows the response data collected after the JCO accident to be compared with the other data.

Using the overall attitude indices, we compared the data for 1993, the data for 1998, and the data collected after the JCO accident. The comparison shows that, in spite of the two accidents between 1993 and 1998, the

Table 7.5 Eight Question Items Used as Overall Attitude Indices

Importance of nuclear power generation	Usefulness of nuclear power generation
Power generation methods that the respondent thinks suitable for the mainstream	Whether or not nuclear power generation can be used wisely
Degree of sympathy with newspaper stories claiming that nuclear power is safe	Number of respondents who support nuclear power generation and number who oppose it
Anxiety about nuclear facility accidents	Opinions on the use of nuclear power generation

"favorable" attitude during this period tended to increase in terms of statistical significance toward support of nuclear power generation. Two months after the JCO accident in 1999, however, the "very unfavorable" attitude increased in terms of statistical significance toward opposition, showing the impact of the JCO accident. It must be added, however, that the comparison of the data for 1993 and the data collected after the JCO accident does not exhibit a significant difference and that the trend derived from the data collected since 1993 does not show remarkable changes toward an unfavorable attitude to nuclear power generation.

The results of this comparison over time can be summarized as follows: Although anxiety about nuclear facility accidents increased slightly during the period in which the three accidents occurred, the nation's passively favorable attitude toward nuclear power generation did not change. The general attitude toward nuclear power generation did not show a negative tendency when evaluated over the entire period beginning with the initiation of the survey. There has been no change in the figure of 60% of respondents passively favoring nuclear power generation as "unavoidable" or in the stratum actively favoring nuclear power generation.

CHANGES IN THE IMAGE OF ORGANIZATIONS AFTER THE JCO ACCIDENT

Changes in the Image of Management and Workers at a Nuclear Power Station

The time series data showed no remarkable change in opinions on the use of nuclear power generation. Using data collected before and after the JCO accident to examine changes in the image of management and workers at a nuclear power station, we shall consider the impact of the JCO accident.

First, we shall examine changes in the image of management (see Figure 7.8). For the periods before and after the accident, both the negative image of power station management as "concealing information" and the

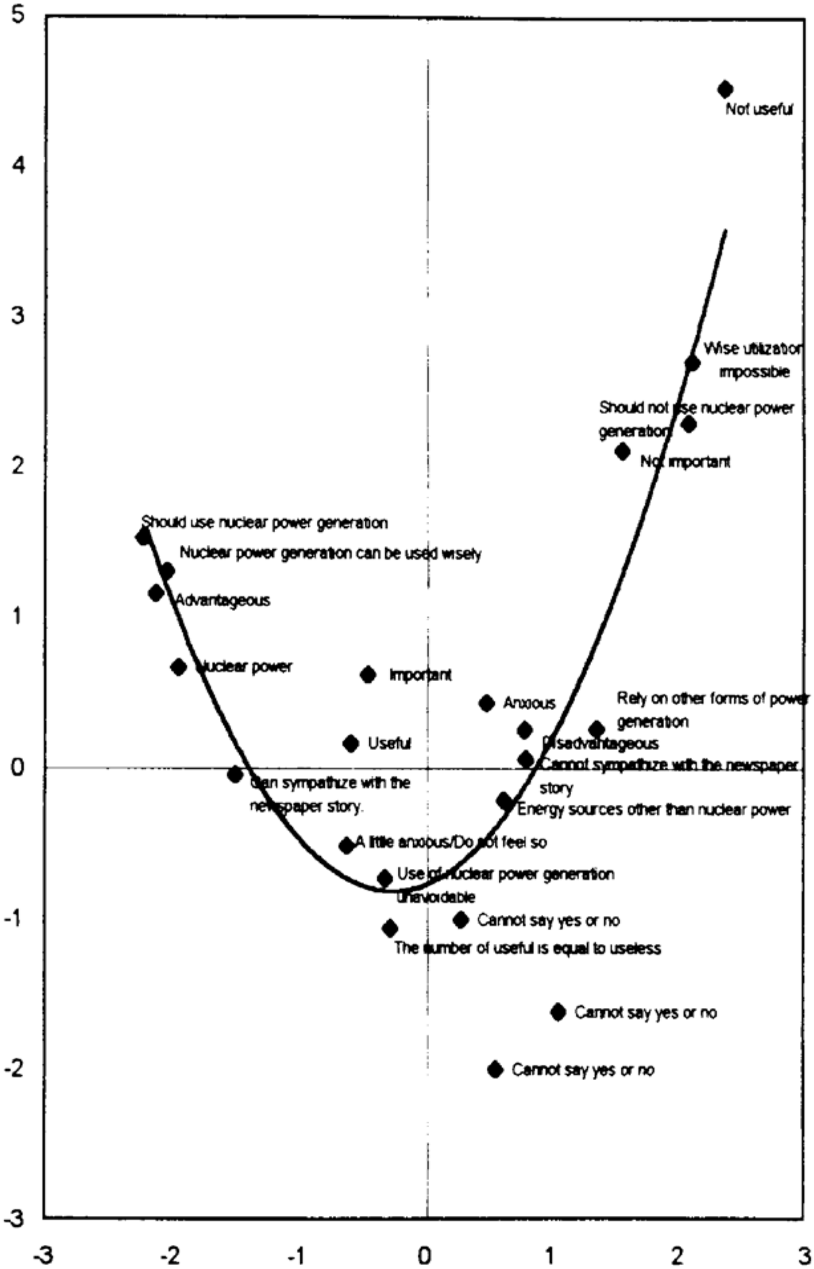

Figure 7.6 Quantification of items related to nuclear power generation; Type III, Axis 1 and Axis 2

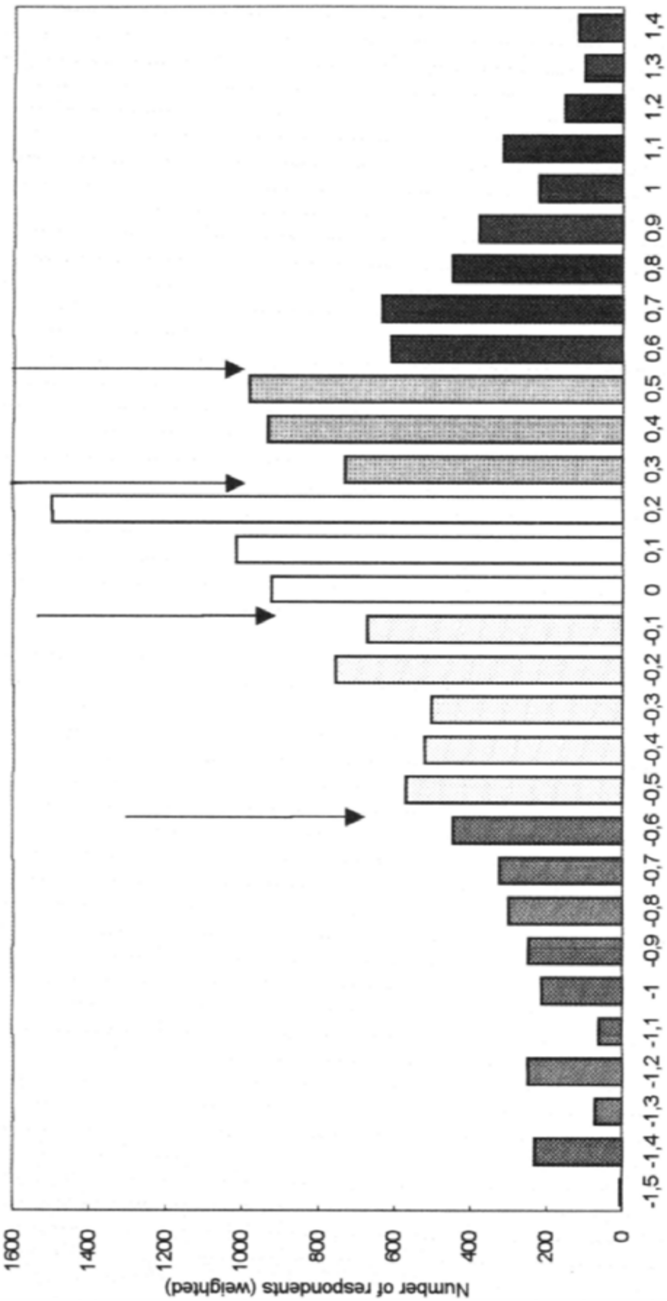

Figure 7.7 Distribution of scores given to respondents for the 1993 and 1998 surveys. The score value distribution has been sectioned at the values indicated by the arrows.

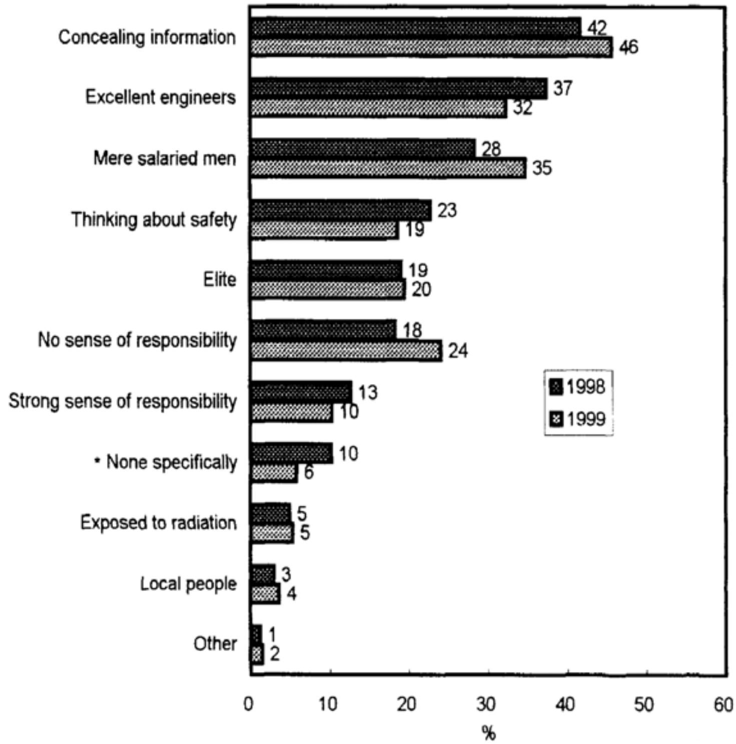

Figure 7.8 Images of nuclear power station management An asterisk (*) indicates statistical significance

positive image of power station management as “excellent engineers” were frequently chosen by respondents. After the JCO accident, the positive image of power station management as being “excellent engineers” and “thinking about safety” decreased, whereas the negative image of power station management as “concealing information,” being “mere salaried men,” and having “no sense of responsibility” increased. However, neither the positive image nor the negative image exhibited a significant difference. An image of power station management as being closed to the outside and lacking a sense of mission became slightly evident.

We shall now examine changes in the image of workers in a nuclear power plant (see Figure 7.9). The most frequently held image of nuclear power station workers is that they obtain their “compensation in return for danger” and work in an “environment exposed to radiation.” Both descriptions reveal an image of the nuclear power station as a dangerous work environment. After the JCO accident, the image of nuclear power station workers as obtaining their “compensation in return for danger” rose by seven points in

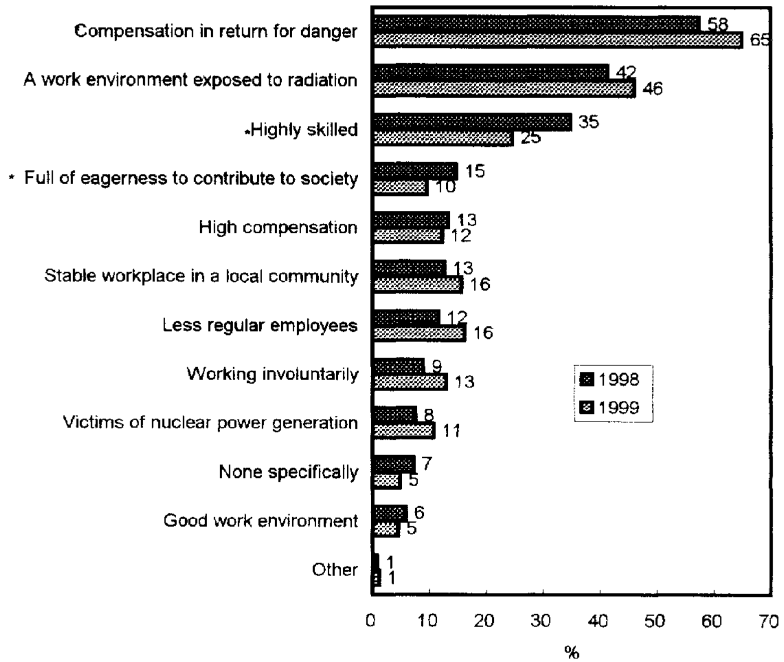

Figure 7.9 Images of workers in nuclear power stations. An asterisk (*) indicates statistical significance.

terms of statistical significance, showing a heightened awareness of danger. After the JCO accident, the image of nuclear power station workers as "highly skilled" fell from 35% to 25%, and the image of workers as "full of eagerness to contribute to society" dropped from 15% to 10%.

The JCO accident was caused in a uranium fuel processing factory by workers who were not aware of the danger of their work and who neglected the safety rules while carrying out a procedure. The questionnaire asks respondents not about what image they hold of workers in a uranium fuel processing factory but rather about the image they hold of nuclear power station workers. Changes were seen in the items corresponding to the issues that drew public attention because of the JCO accident. Images of nuclear power station workers as being "victims of nuclear power generation," "working involuntarily," and consisting of "less regular employees" increased, though these increases did not attain statistical significance. This outcome shows that as the awareness of danger increases, the negative image of nuclear power station workers tends to become pronounced.

Changes in Activities an Electric Power Utility Is Expected to Take

We also examined what kind of activities an electric power utility operating nuclear power stations is expected to take. These surveys were conducted by showing the respondent 14 items, each provided with an explanation, and asking the respondent to select 5 from the 14 with which they can sympathize. The items selected by the respondent can be regarded as a reflection of the image he or she expects from an organization operating nuclear power stations (see Figure 7.10).

The top items chosen by the majority of respondents were "thorough inquiries into the cause of an accident," "disclosure of information at the time of the occurrence of an accident," and "preventive measures against accidents." This outcome suggests that the two most important factors for an electric utility company to win public sympathy are its handling of an accident and its efforts to prevent accidents.

The items that achieved statistical significance in the ratio of selection before and after the JCO accident are the "employee education" item, which rose from 35% to 46%, and the item "activities for living together with communities," which fell from 16% to 9%. With regard to the JCO accident, the government report pointed out that the employees did not have enough knowledge about the danger of a criticality and that employee education on safety was insufficient. It is thought that the JCO accident caused the ratio of selection of the item on employee education to rise.

The survey after the JCO accident in 1999 was conducted not long after the preceding one conducted in 1998. It is very likely that the changes in image over this period resulted from the impact of the JCO accident. In other words, the impact of an accident went as far as to affect and lower the image of nuclear power stations and their organizations.

SUMMARY

The awareness surveys conducted by the institute have made it clear that the images of people operating nuclear power stations and their organizations are closely related to public opinions on the use of nuclear power generation. When people believe that they can trust an organization with the operation of a nuclear power station, they also have positive opinions on the use of nuclear power generation. Public acceptance is prerequisite if nuclear power generation is to continue to play an important role as a major energy source. Hence, it is important that nuclear power stations produce an image worthy of the public trust.

There has been no change in the majority opinion on the use of nuclear power generation since the three recent accidents in nuclear facilities. But an increase in anxiety about accidents in nuclear power stations and worsened

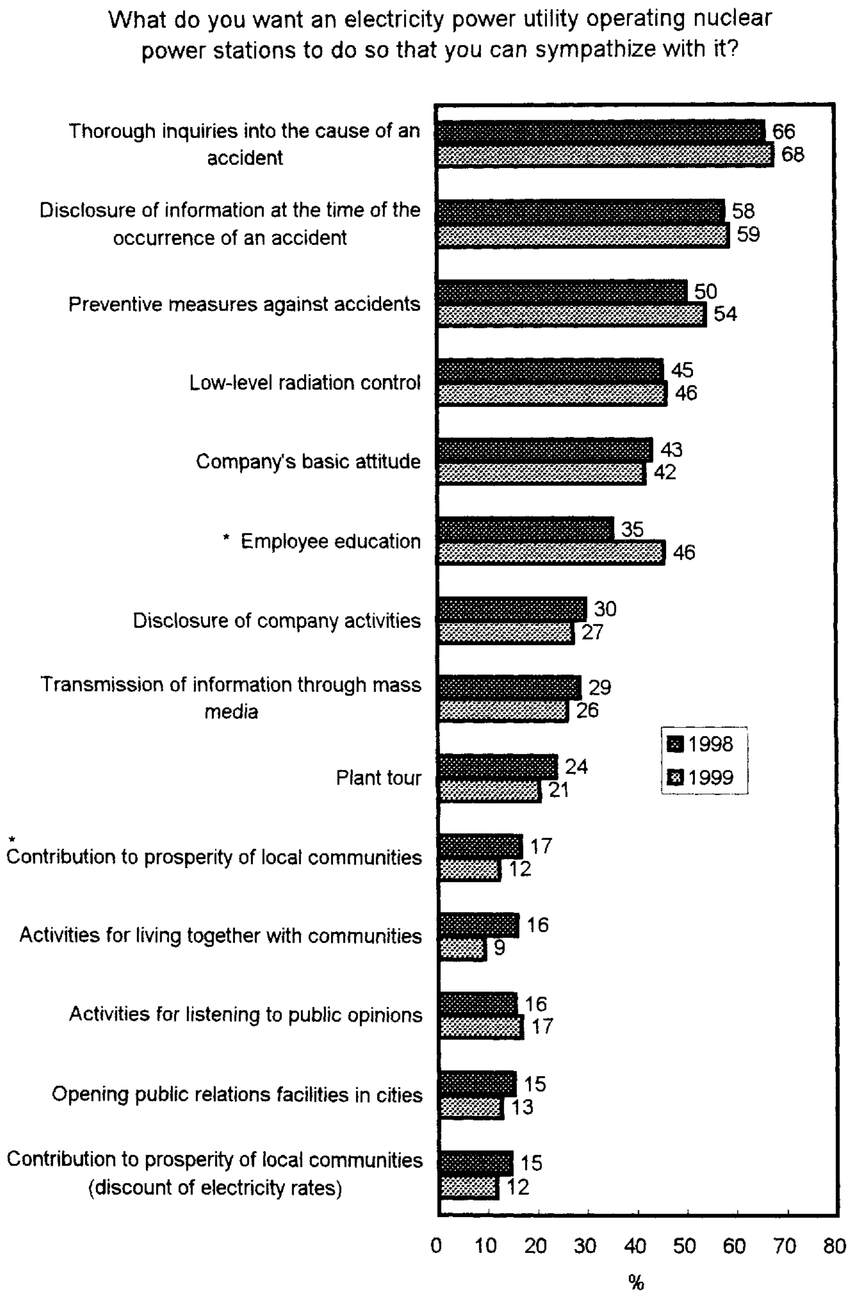

Figure 7.10 Activities that generate sympathy with electric utility companies operating nuclear power stations. An asterisk (*) indicates statistical significance.

images of the organizations generating nuclear power were observed just after the JCO accident. The facility where the accident occurred was not a commercial nuclear power station. However, once an accident occurs, the public tends to expand the image of the accident to similar organizations. Should an event inviting distrust somehow occur in a nuclear-related facility, the impact of the event spreads distrust beyond the boundaries of a single organization, lowering the image of all organizations associated with nuclear power generation.

The general tendency of public opinion on the use of nuclear power generation is a passive attitude that views nuclear power generation as unavoidable. It is feared that, should a situation that would drastically lower trust in organizations operating nuclear power generation occur, opinions on the use of nuclear power generation may change. To avoid such a situation, it is essential that major accidents do not take place. Various approaches that take technological and human factor aspects into consideration have been developed for this purpose. One approach is to create an organizational climate that gives safety first priority. This approach not only is useful for preventing the actual occurrence of an accident but also contributes to establishing an image of trust that convinces the public that the organization operating nuclear power generation has a safety culture. The achievement of these goals will create the groundwork for the public's acceptance of nuclear power generation.

PART THREE

Safety management in nuclear industry

Introduction

This part offers a variety of general nuclear safety management perspectives and techniques as they relate to the role of organizational and managerial factors in assuring safety.

Weil and Apostolakis start from the premise that organizational factors and management cut across different functional domains by creating work environments. Hence, they exert a pervasive influence on safety practices. The authors describe the incident analysis method Work Process Analysis Model (WPAM) and, by way of a case study, apply it to an unusual event, thus demonstrating the method as an efficient means to identify safety-relevant organizational and managerial factors.

After looking at the safety record of different Japanese industrial domains, Kuroda discusses the recent accident of the Tokai-mura uranium processing plant of JCO Company in terms of the consequences of a deteriorating safety culture.

The two chapters by Wahlström and by Takano, Kojima, Hasegawa, and Hirose highlight the need for better (self-)assessment methods for the analysis of the impact of organizational factors on safety. Wahlström reports on the results from a recent European Community-funded study on organizational factors and nuclear safety and similar Finnish studies. Takano et al. show the interrelationship of organizational factors and safety performance by using data on occupational accidents in the Japanese construction and petrochemical industries. This preliminary study may also be considered a demonstration of an appropriate method as well for analyzing the relationships of organizational factors and systems failures in the nuclear industry.

Carroll and Hatakenaka report on a thorough in-depth case study of organizational and managerial problems in a nuclear power plant and how these problems were overcome by internal and external actors and interventions. The study richly illustrates the intricate interrelationships between leadership and the introduction and maintenance of a sustained positive safety culture. The theme is echoed on a national scale in the chapter by Colas, which describes the efforts of Electricité de France to introduce a coherent national safety management strategy in the French nuclear industry.

The chapter by Fahlbruch describes a novel incident analysis methodology, Safety through Organizational Learning, which, different from received checklist approaches, uses a distinct problem-solving approach in order to overcome analytic biases in incident analysis, thus offering a well-tested management tool for corrective action.

CHAPTER EIGHT
Identification of Important Organizational Factors Using Operating Experience

RICK WEIL AND GEORGE APOSTOLAKIS

Important organizational factors with respect to their impact on nuclear power plant performance are identified using an incident investigation methodology developed to determine the contribution of organizational factors to significant incidents. Since nuclear power plants rely on work processes to coordinate work, work processes are an integral part of this methodology. In applying the methodology to significant incidents, several conclusions have been reached. 1) Significant incidents are not the result of single failures. Rather, they are a combination of both hardware and human failures to which organizational factors are significant contributors. 2) Organizational factors, although pervasive throughout the organization, do not exert significant influence everywhere in the organization. They have a pronounced influence on the successful outcome of particular tasks within work processes. Goal prioritization, for example, has been identified as an important factor due to its importance in the prioritization task of various work processes. 3) Many work processes have certain tasks, such as prioritization, in common. 4) As a result of this sharing of tasks, the potential for common-cause failures between dissimilar components exists. Due to the scarcity of information on the contributions of organizational factors to incidents, common-cause failures involving organizational factors could not be demonstrated conclusively. However, there are indications that this area needs further review.

Nuclear power plants have redundancy and diversity designed into them in accordance with the defense-in-depth philosophy. As a result, several defenses must be breached in order to defeat their safety systems. We have found, in agreement with others analyzing significant incidents, that such incidents are the result of several different breakdowns occurring simultaneously, or within a short time interval (Barriere et al., 1998; Reason, 1990; Reason, 1997; Embrey, 1992). Typically, such incidents involve an initiating event, and one or more equipment failures, coupled with an operator error(s).

When the causes for initiating events and equipment failures are identified, most often human errors are partly, if not solely, responsible (Gordon, 1998; Bea, 1998). Furthermore, at the root of the majority of these human errors are organizational factors (Gordon, 1998; Bea, 1998; Papazoglou and Aneziris, 1999; Becker, 1997).

In this chapter, a methodology of incident investigation is presented whose aim is to identify organizational and managerial weaknesses that have contributed to significant incidents. This methodology has been applied to several incidents. The results of these analyses are used to identify important organizational factors with respect to their impact on human performance and to identify the context in which particular organizational factors have the greatest influence.

In addition to developing the incident investigation methodology and identifying important organizational factors, the potential for common-cause failures was investigated. As pointed out in the Work Process Analysis Model (WPAM) (Davoudian, Wu, and Apostolakis, 1994a) and the Socio-Organizational Contribution to Risk Assessment and the Technical Evaluation of Systems (SOCRATES) (Blackman et al., 1998), organizational deficiencies cut across functional groups. Therefore, their influence is pervasive and the potential for common-cause failures of equipment exists not only between similar components, as traditionally modeled in probabilistic risk assessments (PRAs), but between dissimilar components as well, whose failures are not modeled in PRAs. The example presented illustrates how one organizational deficiency could disable dissimilar components.

BACKGROUND

Latent Conditions and Human Error

Traditionally, the investigation of incidents has focused on the identification of human errors, termed unsafe acts, that breach the defenses of an organization. Recently, however, the human reliability community has broadened this scope to include not only the identification of unsafe acts, but the context within which these unsafe acts occur. As previously mentioned, organizational factors play a central role in determining this context.

Following the framework established by Reason, fallible decisions, can lead to line management deficiencies, which can form psychological precursors of unsafe acts, precipitating an unsafe act (Reason, 1990).

Fallible decisions are decisions which high-level managers and designers make that turn out to adversely affect safety and/or reliability. This classification is not meant to provide a means for allocating blame. Rather, it is made in recognition of the fact that, even in well-run organizations, a number of high-level influential decisions will wind up contributing to incidents.

Line management deficiencies can result from fallible decisions, but fallible decisions are not a necessary condition. Errors at the line management level can have the effect of causing good decisions to have bad effects, or could further exacerbate a bad decision. On the other hand, competency at the line management level could mitigate the unsafe effects of fallible decisions, cause neutral decisions to have safer consequences, and turn good decisions into better ones.

Psychological precursors lay the ground work for a variety of unsafe acts at the individual level. These precursors represent a set of conditions which define the mind set of the individual as that individual is affected by the environment, hazards, and culture of the organization. There is a many-to-many mapping between these precursors and the unsafe acts that may result. The specifics are a complicated function of the particulars involved and the task being performed.

An unsafe act is an active error or violation committed in the presence of a particular hazard. While an unsafe act may be the culmination of several latent conditions, a significant incident cannot happen unless several defenses are breached. Latent conditions are defined as those conditions beyond the scope of individual psychology which facilitate the commission of unsafe acts, i.e., fallible decision and line management deficiencies (Reason, 1997). Therefore, there is an important distinction between active failures, latent failures, and latent conditions.

An active failure is characterized by having an immediate effect on the system and is committed at the man-machine interface. They are the result of unsafe acts committed by operators and maintenance personnel. Latent failures are a class of active failures which lay dormant in the system, i.e., undetected maintenance errors which introduce faults into the system. Therefore, the relationship between active and latent failures is clear. Latent failures are active failures which go undetected. Latent conditions are similar to latent failures in that they lay dormant, but differ from latent failures in that they lay dormant in the organization, not the technological systems.

It is widely recognized that in order for a significant event to occur, several factors must be present. As pointed out in the methodology titled "A Technique for Human Event Analysis" (ATHEANA) (Barriere et al., 1998), a combination of equipment failures or unavailabilities, instrument problems, or other complicating factors contribute to unsafe acts on the part of operators, resulting in a significant event.

While much work on human reliability assessment has focused on improving operator reliability, latent condition reduction techniques, which may provide a greater performance benefit, have not received the attention they deserve. In analyzing significant events, we have noticed that both latent conditions and active errors contribute to the event, but that latent conditions do, in fact, play a more dominant role in agreement with the conclusions of Reason. Since latent conditions play a dominant role in significant events and those conditions are caused by organizational deficiencies, what remains to be done is to develop a methodology for event investigation that identifies these organizational deficiencies.

Organizational Factors

To date, there has been a split in the human reliability community between the roles organizational factors and human factors play in system safety and reliability. While recognizing that the two classes of factors are intermingled and related, they are studied as separate and distinct from one another (Gordon, 1998). It is the premise of this chapter that the two classes of factors are, in fact, intimately related because organizational factors shape the context that leads to unsafe actions.

One of the first attempts to identify and define organizational factors which affect safety was performed by Jacobs and Haber (Jacobs and Haber, 1994). Their research identified twenty organizational factors (shown in Table 8.1) related to nuclear power plant safety. The twenty factors were further separated into five categories that characterize the functions of an organization. These categories are: administrative knowledge, communications, decision making, human resource allocation, and culture. While these twenty factors are an adequate starting place, they are too numerous for use in an efficient incident investigation methodology. Several factors need clarification and some are too encompassing to benefit the organization. Furthermore, the specific organizational context within which these factors are important must be determined.

PROGRAMS, PROCEDURES, AND WORK PROCESSES

In order to understand how organizational factors contribute to incidents, it is necessary to understand how organizations structure themselves. In general, organizations have two fundamental characteristics: the division of labor and the coordination of effort (Galbraith, 1973). The division of labor is necessary so that individuals can specialize in order to perform the myriad of tasks required. Coordination of these tasks is necessary so that the organization can work as a unit to accomplish its goals.

Table 8.1 A list of organizational factors (adapted from Jacobs and Haber, 1994)

Categories	Definitions of Organizational Factors
Culture	**1. Organizational Culture**: refers to plant personnel's shared perceptions of the organization. It includes the traditions, values, customs, practices, goals and socialization processes that endure over time and that distinguish an organization from others. It defines the 'personality' of the organization. **2. Ownership**: refers to the degree to which plant personnel take personal responsibility for their actions and the consequences of the actions. It also includes commitment to and pride in the organization. **3. Safety Culture**: refers to the characteristics of the work environment, such as the norms, rules, and common understandings, that influence plant personnel's perceptions of the importance that the organization places on safety. It includes the degree to which a critical, questioning attitude exists that is directed toward plant improvement. **4. Time Urgency**: refers to the degree to which plant personnel perceive schedule pressures while completing various tasks.
Communications	**5. Communication-External**: refers to the exchange of information, both formal and informal, between the plant, its parent organization, and external organizations (e.g., NRC, state and public). **6. Communication-Interdepartmental**: refers to the exchange of information, both formal and informal, between the different departments or units within the plant. It includes both the top-down and bottom-up communication networks. **7. Communication-Intradepartmental**: refers to the exchange of information, both formal and informal, within a given department or unit in the plant. It includes both the top-down and bottom-up communication networks.
Decision-making	**8. Centralization**: refers to the extent to which decision-making and/or authority is localized in one area or among certain people or groups. **9. Goal Prioritization**: refers to the extent to which plant personnel understand, accept and agree with the purpose and relevance of goals. **10. Organizational Learning**: refers to the degree to which plant personnel and the organization use knowledge gained from past experiences to improve future performance. **11. Resource Allocation**: refers to the manner in which the plant distributes its financial resource. It includes both the actual distribution of resources as well as individual perceptions of this distribution. **12. Problem Identification**: refers to the extent to which the organization encourages plant personnel to draw upon knowledge, experience, and current information to identify problems.

Categories	Definitions of Organizational Factors
Administrative knowledge	**13. Coordination of Work**: refers to the planning, integration, and implementation of the work activities of individuals and groups.
	14. Formalization: refers to the extent to which there are well-identified rules, procedures, and/or standardized methods for routine activities as well as unusual occurrences.
	15. Organizational Knowledge: refers to the understanding plant personnel have regarding the interactions of organizational subsystems and the way in which work is actually accomplished within the plant.
	16. Roles/Responsibilities: refers to the degree to which plant personnel and departmental work activities are clearly defined and carried out.
Human resource administration	**17. Performance Evaluation**: refers to the degree to which plant personnel are provided with fair assessments of their work-related behaviors. It includes regular feedback with an emphasis on improvement of future performance.
	18. Personnel Selection: refers to the degree to which plant personnel are identified with the requisite knowledges, experiences, skills and abilities to perform a given job.
	19. Technical Knowledge: refers to the depth and breadth of requisite understanding plant personnel have regarding plant design and systems, and of phenomena and events that bear on plant safety.
	20. Training: refers to the degree to which plant personnel are provided with the requisite knowledges and skills to perform tasks safely and effectively. It also refers to plant personnel perceptions regarding the general usefulness of the training programs.

In nuclear power plants, labor is initially divided according to specific functions: maintenance, instrumentation and control, operations, and plant support to name a few. Labor is further subdivided in departments in order to meet the different requirements necessary to achieve the goal of the department. In addition to subdivisions within departments, people from different departments are grouped together in teams, such as a root cause analysis team. Regardless of how organizations divide and subdivide labor, each separate unit will have its own objectives. The maintenance department has as its objective to ensure that the material condition of the plant is maintained, while the root cause analysis team has as its objective to find the root causes of incidents.

No matter which organizational structure a plant decides on, it must coordinate the work of different units to assure that not only are the needs of each unit being met, but that the individual objective of each unit is compatible with the overall objective of the organization. Nuclear power plants, like many other industrial facilities, may be described by what is known as a *machine bureaucracy,* namely, 'highly specialized, routine operating tasks,

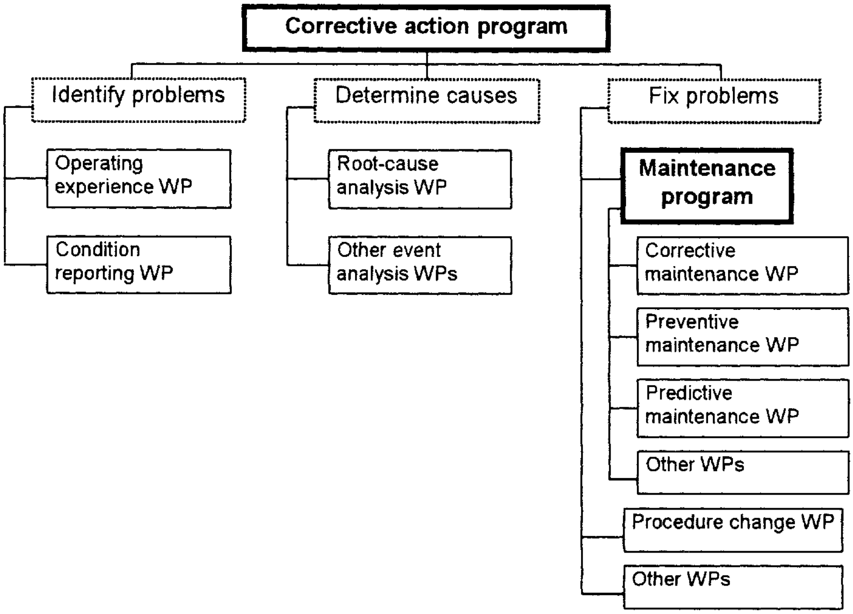

Figure 8.1 Corrective action program and associated work processes (WPs)

very formalized procedures in the operating core, large-scale units at the operating level, reliance on the functional basis for grouping tasks, relatively centralized power for decision making, and an elaborate administrative structure with a sharp distinction between line and staff' (Mintzberg, 1979). As illustrated by Davoudian, Wu and Apostolakis, machine bureaucracies rely on work processes as their prime coordinating mechanism (Davoudian, Wu and Apostolakis, 1994b). A work process is defined as a standardized sequence of tasks that coordinates activities of an organization to achieve a specific goal. An example of a work process is shown in Figure 8.3. Each task in the process is, in general, performed by a different team.

Returning to the maintenance department and root cause analysis team, both have to meet their stated objectives. However, in order for the maintenance department to meet its objective, it needs input from the root cause team as to the causes of certain equipment problems. In order for the root cause team to determine the root cause, they may require input from operations, engineering, as well as other departments. The coordination between the different units is accomplished by work processes.

In order to understand how work processes coordinate work, it is necessary to understand their place in the overall organizational structure. Plants use programs and procedures to conduct their activities. Although the term "work process" has become more commonly used, it is not always present in plant documents. As a result, there is a mismatch between the terminology used in the literature and the terminology used by the industry. Many times what the industry refers to as a program is actually a work process as defined in the literature. In addition, many plants refer to programs as administrative procedures adding to the confusion between work processes, programs, and procedures.

At plants, programs are manifestations of high-level policy objectives. In order to meet those high-level objectives, different goals are identified as necessary to achieve the high-level objectives. In order to help plant personnel meet those goals, different responsibilities are assigned to different plant personnel and guidance is provided as to what they must do. Usually programs are formed in response to a regulatory request. For example, the stated high-level objective of the Corrective Action Program at one plant is to ensure that degraded plant, process, or human performance conditions are corrected as soon as practicable commensurate with their importance to the health and safety of plant personnel and the public. In order to achieve that objective the program requires that plant personnel review events, categorize their significance, evaluate their circumstances, and determine corrective actions to prevent their reoccurrence. In the program documentation, different responsibilities are assigned to several different plant personnel and guidance is provided for such activities as condition reporting, event evaluation, trending, and monitoring. The guidance provided to achieve specific goals, referred to as administrative procedures, housed in program documents at plants, are work processes. The relationship between the corrective action program and the work processes associated with it is shown in Figure 8.1. The connection between work processes and programs is that a program is a collection of work processes.

Although this hierarchical relationship between work processes and programs appears to work well, there is a problem due to the way that different plants structure their programs. There is no standardized way to structure programs. As a result, different plants have different programs. Some plants have programs nested within programs, while others have programs separate from one another. For example, some plants have a maintenance program with preventive maintenance activities and corrective maintenance activities. On the other hand, other plants have a maintenance program with a preventive maintenance program and a corrective maintenance program within it. With respect to preventive and corrective maintenance, one plant has three programs, while the other has only one. In both cases there are only two work processes, namely the preventive and corrective maintenance work processes. Regardless of how many programs a plant organizes itself into, it is the work processes that coordinate the work, not the programs. Since the work performed by the plants is very similar, despite the differences in the structure of the programs, the work processes are nearly identical.

In addition to programs, plants use procedures to conduct work activities. Plants generally have different classes of procedures, such as administrative, maintenance, and operational. The difference between administrative procedures and the other two are that administrative procedures provide guidance on how to accomplish a general task such as planning, whereas operational and maintenance procedures provide explicit instructions on how to perform a specific task, such as repairing a component or performing a valve stroke test. Regardless of the type of procedure, a procedure can be defined as a sequence of steps designed to perform a specific task.

At this point, the relationship between programs, procedures, work processes, tasks, and steps is reiterated. Recall that plants divide and subdivide labor in order to allow for specialization. As a consequence of these divisions, work must be coordinated in such a way to ensure that each unit receives the necessary input it needs so that it can meet its objective and that the different unit objectives are compatible with the overall objective of the organization. The prime coordinating mechanisms that plants use are work processes. A work process is a sequence of tasks designed to achieve a specific goal. Procedures are sequences of steps that provide guidance on how to perform a particular task. They can be explicit, as is the case with operational or maintenance procedures, or can be more general, as is the case with administrative procedures. We emphasize that a work process is carried out by a number of teams at different times, while a procedure is usually implemented by one team. Lastly, a program is a term used by plants to organize groups of work processes. Since plants do not generally use the terms work process and task, these terms are frequently misused.

HUMAN RELIABILITY, WORK PROCESSES, AND THE WORK PROCESS ANALYSIS MODEL (WPAM)

Although the precise connection between managerial & organizational factors and human reliability has yet to be determined, it is clear that a reduction in organizational deficiencies will lead to an increase in human reliability and subsequently to increased plant performance.

As mentioned earlier, nuclear power plants, like many other industrial facilities, exhibit characteristics of what is known in organizational theory as a machine bureaucracy. As a result of this organizational structure, nuclear power plants rely on work processes to conduct activities. Recognizing that work processes are the prime coordinating mechanisms at plants, WPAM was developed.

One of the goals of WPAM is to understand how the organization works and what can go wrong (Apostolakis, 1999). In answering that question, a task analysis is performed. The output of the task analysis is a flow diagram (shown in Figure 2) accompanied by a cross reference table, and an organizational factors matrix. Each box on the flow diagram is an individual

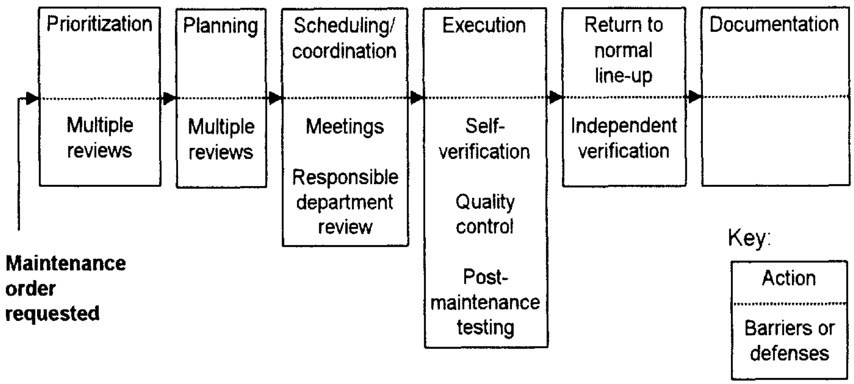

Figure 8.2 The flow diagram for the corrective maintenance work process (Davoudian, Wu, and Apostolakis, 1994b, p. 92)

task. The top portion shows the action performed and the bottom portion shows the defenses used to catch any errors that may have occurred. For example, in the corrective maintenance work process, looking at the task of prioritization, we see that the action is prioritization and the defenses are multiple reviews. The cross-reference table (not shown) provides an easy way to see who performs an action or defense and which department they are in. Finally, the organizational factors matrix (not shown) maps the organizational factors to specific tasks (Davoudian, Wu and Apostolakis, 1994b).

As shown in Figure 8.2, the corrective maintenance work process is made up of several tasks. The majority of maintenance errors cited in incident investigations occur in the execution task. However, many times contributing factors, committed in other parts of this or other work process(es), contribute to the commission of the unsafe act in the execution task. For example, if procedures referenced in a work package are not appropriate for a specific task and a maintenance error results, a contributing cause is an error that occurred in the planning task. Another example is when procedures referenced in work packages are deficient. In this case, a contributing cause is the deficient procedure. This indicates an error somewhere within the procedure writing work process.

Although the total number of work processes at plants is large, they are not all equally important with respect to performance. Maintenance work processes, design change work processes, condition reporting work processes, and operating experience work processes are some of the more important work processes. Performing a task analysis on these different work processes we notice several similarities between them. Invariably, they all have a prioritization and documentation task. Additionally, maintenance and design change work processes share planning and scheduling tasks. Other work processes exhibit a similar sharing of tasks. The reason that these similarities are important is because certain organizational factors influence the successful outcome of a particular task. Therefore, if an organization is deficient in one factor which is important in achieving the successful outcome of a task in common to several different work processes, prioritization for example, then several errors in different work processes affecting many different areas of the plant can be expected. This directly points to the possibility for common-cause failures (see respective section below).

In an attempt to link organizational factors to the activities carried out at nuclear power plants, and recognizing that work processes are central to the conduct of these activities, the Work Process Analysis Model (WPAM) is used in the incident investigation methodology presented. The strength of WPAM is that it models the way in which plants actually conduct work. In this work, since work processes are grouped together in programs at plants, WPAM was expanded to include programs as well as work processes. By using WPAM in our methodology, we can:

- Link specific organizational deficiencies, i.e., weak organizational factors, to specific tasks within a work process
- Guide analysts to specific organizational factors depending upon within which task an error occurs
- Guide analysts to other work processes based on the type of errors identified
- Have a mental model of the plant's coordination and execution of work
- Identify latent conditions by tracing errors back to their organizational roots

RESULTS

Six Important Organizational Factors

Our efforts to identify the most important organizational factors affecting human performance from the list of twenty factors has two objectives. One is to increase the efficiency of the incident investigation methodology by providing the investigator with fewer factors to look for and the context in which they would appear. The second is to trim the original list of twenty into a more manageable list by eliminating those factors that do not greatly impact performance. This is accomplished by a combination of lumping factors together, identifying redundancies, identifying less important factors, and most importantly by using industry operating experience to identify important factors with respect to performance. To that end, six factors and the tasks in which they influence successful outcomes have emerged. These organizational factors, their definitions (adapted from Jacobs and Haber's definitions shown in Table 1), and the tasks they influence are shown in Table 8.2.

The first observation from Table 8.2 is the absence of safety culture, organizational culture, and organizational learning. This in no way implies that these factors are not relevant to plant performance. In fact, safety culture and organizational learning may be the most important factors influencing performance (Reason, 1997; Sewell, Khatib-Rahbar, and Erikson, 1999; INSAG, 1991). The reason why these factors, along with organizational culture, are excluded from Table 8.2 is because they are too far-reaching to provide the plant much benefit when cited in an investigation.

The term safety culture is an ill-defined term used throughout the nuclear industry, as well as others, and in the literature. One commonly used definition was proposed by the International Nuclear Safety Advisory Group (INSAG) which defined safety culture as "…that assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, nuclear power plant safety issues receive the attention warranted by their significance" (INSAG, 1991, p1). They further state that "…safety culture has two major components: the framework determined by organizational policy and by management action, and the response of individuals in working within and benefiting by the framework. Success depends, however, on the commitment and competence, provided both in the policy and managerial context by individuals themselves" (INSAG, 1991, p2). This definition essentially states that safety culture is made up of individual attitudes and competencies, organizational culture, and all of the organizational structures required to safely run a plant.

Another definition proposed by Reason describes the four critical subcomponents of safety culture as: "…a *reporting culture,* a *just culture,* a *flexible culture* and a *learning culture*" (Reason, 1997, pp 195–220). This definition is similar to the INSAG definition in that it includes every organizational structure in the plant as well as different aspects of organizational culture. Although both refer to safety culture as a single factor, it is more appropriate to refer to several separate and distinct factors, as well as several different work processes. For example, individual competencies can be represented by technical knowledge and a reporting culture can be represented by organizational factors such as problem identification, and work processes such as the Condition Reporting work process.

As a consequence of their broad definitions, organizational learning, safety culture, and organizational culture can be cited as contributing to most incidents under investigation. Although they are frequently cited as contributing to several incidents, this does not help the plant very much with respect to addressing them. This is because they are cited in many different tasks in different work processes. As a result, it is difficult for the plant to develop a solution to the deficiency. Rather than identify them as

Table 8.2 Important organizational factors

Organizational Factor	Definition	Tasks Influenced
Communication	Refers to the exchange of information, both formal and informal.	Pervasive – Most important between different units and departments
Formalization	Refers to the extent to which there are well-identified rules, procedures and/or standardized methods for routine activities and unusual occurrences.	Execution
Goal Prioritization	Refers to the extent to which plant personnel acknowledge and follow the stated goals of the organization and the appropriateness of those goals.	Prioritization
Problem Identification	Refers to the extent to which plant personnel use their knowledge to identify potential problems.	Planning, scheduling, and return to normal line-up
Roles and Responsibilities	Refers to the degree to which work activities are clearly defined and the degree to which plant personnel carry out those work activities.	Execution
Technical Knowledge	Refers to the depth and breadth of requisite understanding that plant personnel have regarding plant design and systems, and the phenomena and events that bear on their safe and reliable operation.	Job specific knowledge – execution Broad based knowledge –prioritization, planning, scheduling, and other tasks

contributing factors, it would be more beneficial to the plant to identify specific factors which comprise them, and the tasks in which those factors influence successful outcomes. In doing so, the *how, when,* and *where* they contributed to an incident would be identified. For example, instead of citing poor safety culture on the part of plant personnel in the task of planning in the corrective maintenance work process, more specific factors such as lack of problem identification should be cited. Similarly, instead of identifying poor organizational learning, it would be more beneficial to identify the causes for poor organizational learning such as poor goal prioritization or weak technical knowledge on the part of plant personnel in the task of screening in an operating experience work process. By identifying more specific deficiencies, the plant will be better able to address those deficiencies in developing more targeted solutions.

A second observation from Table 8.2 is that some of the factors have been somewhat redefined from their original definitions proposed by Jacobs and Haber (1994) (see Table 8.1). These new definitions are not as straightforward as they appear, therefore some explanatory comments are provided. Communication, as defined, refers to both formal and informal information exchange. This includes written, verbal, and other communications such as actions and body language. Technical knowledge refers to plant personnel's technical background as well as their training in reference to performing certain tasks. Therefore, technical knowledge is intimately tied to training in that training is the vehicle with which plant personnel gain requisite technical knowledge. Note the difference between *training regarding a certain task,* which refers to the training someone received, and the *act of training*. The former is part of that person's technical knowledge, while the latter makes reference to the training work process. Implicit to definition of problem identification is that the organization encourages personnel to identify problems. However, whether or not the organization encourages personnel to identify problems, the quality of this factor is judged by whether or not the personnel identify potential problems. Roles and responsibilities apply to all work activities, specifically in regards to following procedures and the clarity of procedures.

A third observation from Table 8.2 is that several factors have been lumped together. Three groups of factors were lumped together to eliminate overlap. All three types of communication were lumped together into a single factor, communication. Goal prioritization, resource allocation and time urgency were all lumped into goal prioritization. Lastly, ownership and problem identification were lumped into problem identification.

The reason why all three types of communication, external, interdepartmental, and intradepartmental, were lumped together, is because separating them was not necessary. The type of communication, where it occurred, when, and between whom is all captured in the incident investigation methodology through the use of work processes.

Goal prioritization, resource allocation and time urgency were all lumped into goal prioritization because goal prioritization dictates, to a certain extent, the other two. Goal prioritization will directly impact the resource allocation of an organization. An organization will fund certain programs corresponding to the extent it values certain ideals. Additionally, goal prioritization directly impacts time urgency. If an organization values production above safety, workers may feel pressured to maintain the production schedule. Therefore, the tasks of goal prioritization, resource allocation and time urgency are all lumped into goal prioritization.

A case can be made that resource allocation and time urgency are more specific factors and thus it would be more beneficial to the organization to identify them as opposed to goal prioritization in an investigation. The problem with this is that the plant may try to address local problems of time urgency and resource allocation instead of addressing the more global problem of goal prioritization. What should be done in an investigation is to look at instances in which resource allocation or time urgency are suspected. After finding such instances, the investigator should note the task within which it occurred and assess the appropriateness of the plant's goal prioritization as it applies to the particular task. If the investigator determines that a plant's goal prioritization is deficient, then he should recommend that all tasks affected by goal prioritization be examined. For example, if goal prioritization is found to be deficient in the task of prioritization in the corrective maintenance work process, then the organization may want to verify the appropriateness of goal prioritization in all prioritization tasks within the maintenance department and/or other departments.

The last group of factors lumped together are ownership and problem identification. These factors are lumped into problem identification because problem identification is the factor which has the most direct impact on plant performance of the two. Furthermore, identifying ownership may not provide the plant with any benefits. Although we suspect that a high degree of ownership aids in improved problem identification, it is not a necessary condition. What this means is that for some people, a high degree of ownership would spur increased problem identification. On the other hand, others may have increased problem identification because of a strong work ethic, independent of ownership. Additionally, a plant may not have much control over its employees feelings of ownership. Therefore, problem identification is the factor which investigators should look for.

Reasons for Selecting the Six Factors

The identification of important organizational factors was primarily based upon a combination of which tasks they influenced and how frequently their influence resulted in errors. The primary source of operating experience used to determine these criteria was Nuclear Regulatory Commission (NRC) Augmented Inspection Team (AIT) reports. The reason for identifying important factors based on these criteria has to do with the sharing of tasks in different work processes. As mentioned in Section 4, several work processes share tasks. For example, multiple work processes share any one or more of the following tasks: prioritization, planning, scheduling, and execution. If a particular factor, goal prioritization for example, is influential in regards to the successful outcome of a particular task in one work process, for example the prioritization task in the corrective maintenance work process, then it is reasonable to conclude that it has the same influence in the prioritization task in other work processes. As a result, a deficiency in goal prioritization would contribute to errors in multiple work processes. Therefore, one of the criteria used to identify important organizational factors was whether they had a significant influence on the successful outcome of tasks which several work processes have in common.

The other criterion used was how frequently a particular factor was cited as contributing to errors. The reason for this criterion was to place a higher emphasis on those factors which may not contribute to the successful completion of a shared task in multiple work processes, but frequently cause errors in one task of a single work process. Additionally, this criterion allowed us to place lower emphasis on factors which contribute to the successful completion of shared tasks within multiple work processes, but are rarely deficient.

Using the two criteria, communication was identified as one of the most important organizational factors. It is pervasive throughout the organization and nothing would be accomplished in an environment with poor communication. Results from our analysis showed communication contributing to errors in several maintenance work processes in the tasks of planning, scheduling, and execution, and in the procedure writing work process in the task of preparation. In addition to appearing in such diverse tasks, communication was frequently cited as contributing to incidents. Due to its influence in such crucial tasks and its frequency of occurrence, communication is one of the most important organizational factors.

Similar to communication, technical knowledge appears frequently in a variety of work processes in multiple tasks. Our analysis showed a lack of technical knowledge contributing to errors in facility modification work processes in the tasks of design and post-modification testing, in several maintenance work processes in the task of execution, and in operating experience work processes in the tasks of prioritization and evaluation. Although technical knowledge is pervasive, as illustrated by the preceding findings, we identified two types of technical knowledge. The first is fundamental knowledge which relates to the skill of the craft and is specific to particular jobs such as welding and valve packing. The second is a high-level understanding of the different systems and the interactions between systems. While the former type of technical knowledge primarily impacts execution tasks, the latter impacts design, post-modification testing, prioritization, and evaluation. In addition to the aforementioned tasks, we suspect that technical knowledge influences the successful outcome of other tasks such as planning and scheduling. Due to the scarcity data, we have not been able to identify instances in which these other tasks have been affected by a lack of technical knowledge. However, due to the number of different tasks already identified, in several important work processes, technical knowledge is one of the most important organizational factors.

Goal prioritization and problem identification are identified as important factors not only because of their influence in certain tasks, but because of their suspected influence on others. Goal prioritization was cited as contributing to errors in operating experience work processes in the task of prioritization. Although no incidents were cited in which goal prioritization affected the prioritization task in maintenance work processes, it is strongly suspected that it does. The fact that it was not seen in our analysis is, again, attributed to the scarcity of data. Similarly, problem identification was cited as contributing to errors in a maintenance work process in the task of scheduling. Although no incidents were cited in which problem identification contributed to errors in the task of return to normal line up in maintenance work processes, it is strongly suspected that it does. The fact that it was not seen in our analysis is again attributed to the scarcity of data.

The last two factors are formalization and roles and responsibilities. Formalization and roles and responsibilities are factors which contribute to plant personnel not following procedures. Not following procedures almost exclusively contributes to errors during the execution task of work processes; specifically maintenance work processes. Since problems with procedures are so rampant at plants, cited in most incidents, formalization and roles and responsibilities are among the most important organizational factors.

There are several reasons why plant personnel do not follow procedures. The procedures may be vague, ambiguous or otherwise hard to understand, there may have been confusion in the pre-job briefing, or in the supervisors role, and/or the person performing the tasks may skip a step by accident, or decide that there is no need to follow the procedures. The reason why a particular procedure was not followed determines which organizational factor contributed to the incident. In the event that there is a communication problem in transferring information to the people responsible for performing the work, such as is the case when the procedures are ambiguous or there is confusion in the pre-job briefing, formalization is responsible. If a procedure is not followed, roles and responsibilities is responsible. Although a case could be made to cite communication as the organizational factor, instead of formalization, due to the procedurally-dependent nature of plants and the fact that the procedures are complex, formalization is used to capture this specific type of communication problem.

Reasons for Excluding Other Factors

Although it appears that a factor is less important because it is excluded from Table 8.2, this is not always the case. All factors are important in one way or another. As previously mentioned, safety culture, organizational culture and organizational learning are very important to performance, but are not included in Table 8.2 because they do not provide as much benefit to the organization as the others when cited in investigations. Additionally, several factors were lumped together. Furthermore, although centralization, performance evaluation and organizational knowledge are important factors, they were not identified as contributing to any incidents analyzed and are not suspected to contribute to many. Therefore, they received a lower prioritization with respect to performance. Lastly, performance evaluation was not a significant contributor to any incidents investigated, and can be though of as part of organizational learning. Consequently, it was excluded from Table 8.2.

Other factors are excluded because they are captured in other parts of the incident investigation methodology. For example, training is a work process itself and coordination of work is captured in the task analysis of WPAM. Since the factors were identified to aid in the analysis of incidents, if the methodology used to investigate the incidents included an analysis of the areas represented by the organizational factor(s), those factors were excluded to avoid redundancy.

The last factor excluded was personnel selection. Although personnel selection appears to be a significant factor in some incidents, it is usually the lack of technical knowledge which is the significant factor. Since, technical knowledge is included on the list, as well as other factors which contribute to poor personnel selection, and personnel selection is not frequently sighted as a contributing factor, it was excluded from Table 8.2.

INCIDENT INVESTIGATION METHODOLOGY

Methodology

Following an abnormal occurrence, all plants use event analysis techniques to help identify factors judged significant to the occurrence of the incident with the goal of precluding the reoccurrence of the incident and incidents similar to it. Conventional event analysis techniques, however, fall short of their goal when the analysis terminates after only identifying human error(s) and or physical cause(s) of the failure. Research and experience have shown that incidents are often the result of underlying managerial and organizational deficiencies. The methodology presented here identifies these underlying deficiencies. Only after identifying and resolving these deficiencies will the organization be able to fulfill the goals of the event analysis and improve plant performance.

Although it is widely recognized that organizational factors play a crucial role in plant performance, their precise role is unclear. Research from SOCRATES, a project at the Idaho National Engineering and Environmental Laboratory, supports this and states ".. organizational factors are difficult to assess. Although organizational factors affect plant performance the question always posed is *How do they do so?*" (Blackman et al., 1998, p4). We attempt to answer the question of *how organizational factors affect performance* by linking organizational deficiencies to specific incidents through the use of work processes. The methodology presented traces individual human errors to the error forcing context and ultimately to organizational deficiencies. It is a synthesis of human error models, primarily the one developed by Reason (the model of the type-token transformations) in addition to the expansion of traditional root cause analysis by Tuli, Apostolakis, and Wu, 1996) with the use of WPAM. The five steps of the methodology are shown in Figure 8.3.

Step 1:
Description of the Incident

The first step, the description of the event, is probably the most time consuming component of this or any root-cause analysis methodology. In this step, the investigator recreates the incident, determines the conditions prior to the incident and maps out the progression of the incident.

Step 2:
Identification of Hardware Contributors and Operator Contributions

After completing the description of the incident, the investigator begins analyzing it. At this point, the investigator should have a clear idea of the circumstances surrounding the incident, and the failures that caused it. In this step, the investigator begins organizing the incident by separating it into its constituent parts. The number of different constituents depends on the complexity of the incident. In simple incidents such as individual equipment failures, i.e., a valve failing to respond due to a short circuit, there may be only one constituent part; namely, the short circuit. However, in severe incidents, such as scrams accompanied by safety system failures, operator errors, and hardware failures hindering recovery actions, there may be several constituent parts. Each constituent of the incident represents either a piece of hardware or an operator action that contributed to the incident. For the purpose of this methodology, hardware constituents are referred to as 'contributors', whereas human constituents are referred to as 'contributions'.

Step 3:
Classification of Event Constituents as Pre-Initiator or Post-Initiator

Having identified the constituent parts of the incident, they are further separated into pre-initiator and post-initiator. The term initiator does not refer

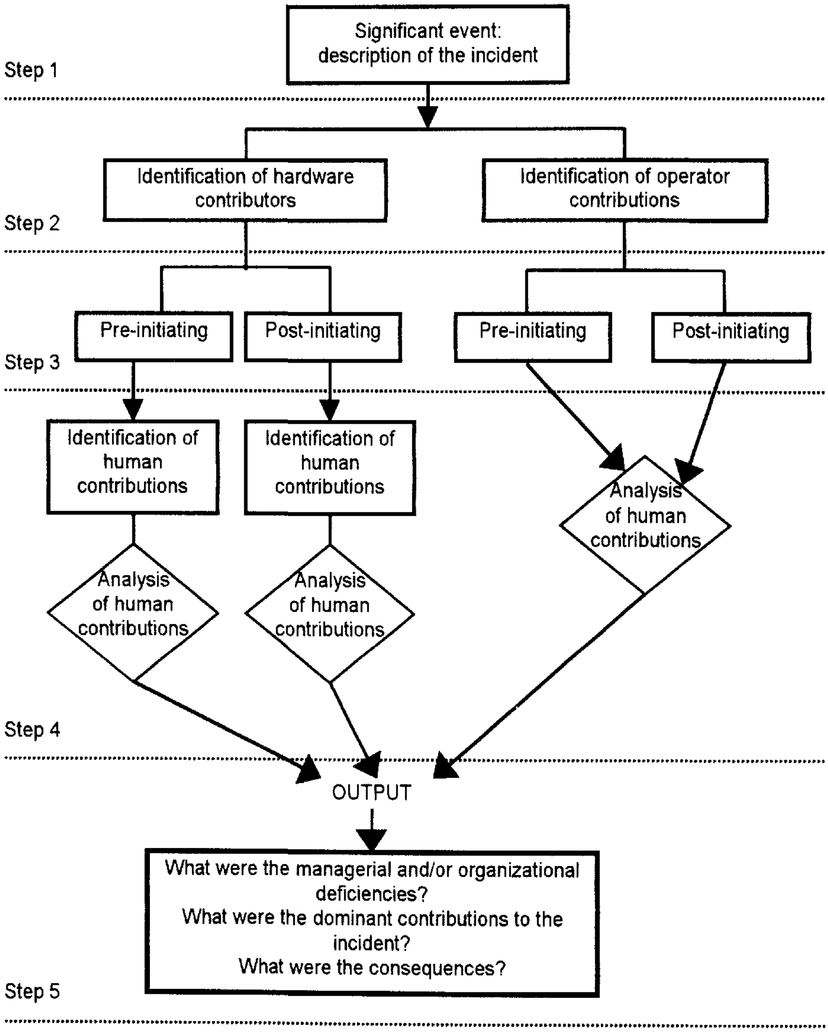

Figure 8.3 A general overview of the incident investigation methodology

to the traditional initiating events found in the PRA vernacular; rather, it denotes the start of the incident under investigation. This distinction is more appropriate for operator contributions than hardware contributors.

Subsequent to the initiation of an incident, if necessary, operators begin recovery actions. During recovery, the context surrounding their actions is markedly different from their actions before the start of the incident. For one, there is usually a higher degree of stress and increased time pressure. Additionally, their behavior could be the more error prone knowledge-based behavior, as opposed to rule-based behavior found in pre-initiator operating conditions (Rasmussen, 1983). Therefore, we would clearly expect to find a much different set of circumstances surrounding the actions of operators in the two different time frames. As a result, the investigator would analyze the two different classes of operator actions from a different vantage point.

Hardware contributors, on the other hand, are not as sensitive to pre-initiator and post-initiator states. The reason is that hardware is not affected by time pressure and stress like their human counterparts.

Step 4: Identification and Analysis of Human Contributions

The next step in the methodology is to determine what, if any, were the organizational deficiencies contributing to the human contributions. Using the hardware contributors as starting points, the investigator identifies their human contributions and traces them back to their organizational roots as shown in Figure 8.4. The investigator analyzes both human contributions to hardware contributors and operator contributions for organizational deficiencies' contributions. Unfortunately, there is no easy way to explain how to identify human contributions, or to analyze them. This task, however, becomes easier with experience.

After identifying a human contribution, its place in the organization, defined by which program it occurred in, which work process, and which task within the work process, is identified. The reason for this is that once the investigator identifies where a human contribution occurred, it suggests additional places to look for other human contributions and contributing factors.

Although Figure 8.4 shows a clear distinction between programs, work processes, and tasks, and implies a hierarchical relationship between them, in actuality, the lines between different programs and even between programs and work processes are blurred. For example, it is not uncommon for a work process to belong to more than one program. Additionally, Figure 8.4 should not be interpreted as a progression from identifying a human contribution, followed by identifying which program, work process, and task in which it occurred. Sometimes the investigator may first identify the task in which the human contribution occurred and then identify which work process and program. Alternatively, the investigator may identify the work process, followed by the task and then the program, or vice-versa. In either case, following the determination of where in the organization the human contribution belongs, organizational deficiencies which facilitated its occurrence are sought. In order to identify organizational deficiencies, human contributions are classified according to the conventions in Section 2.1.

The reason that human contributions are classified according to Reason's terminology is that, depending on the classification, it suggests where to look

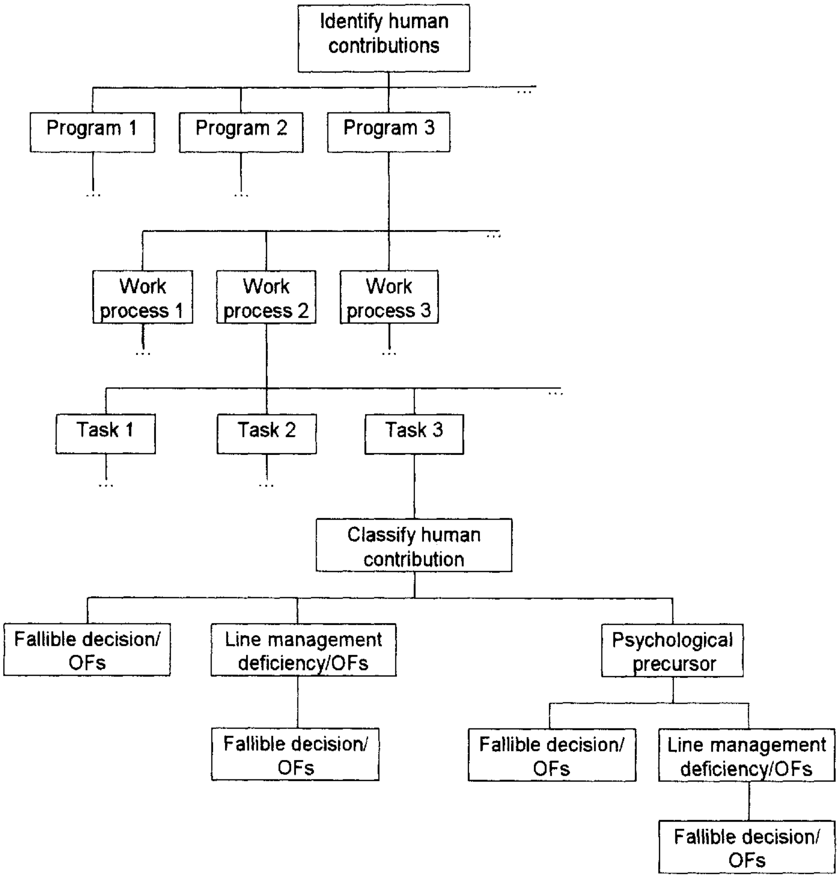

Figure 8.4 Identification and analysis of human contributions

Note. OF=Organizational factor

for organizational deficiencies. For example, if an investigator classifies a human contribution as a psychological precursor, then the investigator may want to look for line management deficiencies and subsequently, fallible decisions contributing to it. Alternatively, if an investigator classifies a human contribution as a fallible decision, he may want to look for other fallible decisions contributing to its occurrence. In this fashion, the investigator will trace human contributions back to their organizational roots.

Although Reason's framework is useful in identifying organizational deficiencies, the investigator should not follow it literally. Despite the fact that Reason's frame work delineates a clear progression from fallible decisions to unsafe acts and ultimately to incidents, this is not the only pathway. In fact, the relationships between the different failure types, failure tokens, and incidents are more complicated. Fallible decisions themselves, such as poor prioritization, can lead directly to incidents. Certain line management deficiencies, which may or may not be the result of fallible decisions, can cause incidents. Furthermore, fallible decisions can influence psychological precursors, without engaging a line management deficiency, or can influence other fallible decisions. This is represented at the base of Figure 8.4.

Step 5:
Output

The methodology culminates with a summary of the analysis which includes the identification of the organizational deficiencies, the dominant contributors, and the consequences of the incident. Additionally, each organizational deficiency is tied to a specific human contribution via the work process.

Example: Plant C-1 Unusual Event

Step 1:
Description of the Incident

On May 19th, 1996, at plant C-1, a malfunction in the feedwater control circuitry caused the feedwater pump to slow inducing a reactor trip due to high pressure. Following the trip, six of eight steam safety valves on Steam Header B opened to relieve reactor pressure. However, one of the six valves, PSV-2685, failed to close. Therefore, as per procedures, operators isolated the B steam generator and allowed it to boil dry. Due to further feedwater control deficiencies, emergency feedwater actuated as designed, providing a decay heat removal source to the A Steam Generator and the condenser. Shortly thereafter, the condenser became unavailable, due to the absence of gland sealing steam normally supplied by the now isolated B steam header. Although the auxiliary boiler would have normally supplied gland sealing steam in this situation, it did not because it had failed. As a result, decay heat removal proceeded through the atmospheric dump valves. It was noted that the atmospheric dump valves did not function in automatic mode as designed and operators were required to take considerable actions to manipulate the block valves to control the cooldown. Later, gland sealing steam was recovered as maintenance had repaired the start up boiler.

Sequence of Events

At 3:11 AM while operating at 100% power, a decrease in speed of feedwater pump A occurred. Feedwater pump B increased output as was demanded by the integrated control system, and then erroneously transferred to the diagnostic manual mode on a valid integrated control system signal. The crossover valve closed and the reactor tripped on high pressure. The integrated control system demanded a rapid decrease in feedwater pump speed, but feedwater pump B was unresponsive since it was in the diagnostic manual mode. Feedwater pump B then tripped on high discharge pressure.

Feedwater pump A had been operating well below its last valid demand signal and was operating below its 0% flow speed of 3000 rpm. The pump was in the manual mode of operation and should have switched to the automatic mode, but was precluded from doing so because it was operating below the minimum speed. After the reactor trip, the fault appeared to have cleared and the pump responded to its last valid demand which was very high. Therefore, feedwater pump A tripped on mechanical overspeed.

Following the reactor trip, emergency feedwater actuation occurred on low level in steam generator B. Although the actual level was not low, the system interpreted it to be low due to a back pressure wave which exceeded the 2s time delay designed to preclude this actuation. The pressure wave was most likely caused by higher than normal flow just before the reactor trip. In response to the increased pressure in steam generator B, six of eight main steam safety valves opened as designed. However, after the pressure decreased, one of the valves failed to reseat resulting in a rapid cooldown of the primary. This resulted in the actuation of high pressure injection in accordance with design.

As designated by procedures, operators isolated steam generator B and allowed it to boil dry. Decay heat removal continued through steam generator A to the condenser. However, the condenser was lost as a heat sink due to a loss of gland sealing steam which was supplied only by steam header B. At this point, the gland sealing steam should have been supplied by the auxiliary boiler, but it was not because the auxiliary boiler required maintenance to operate. Consequently, heat removal proceeded through the atmospheric dump valves and corresponding block valves. It was noted that the atmospheric dump valves did not function in automatic mode as designed and that operators were required to take considerable actions to utilize it as a heat removal path.

Two-and-a-half hours after the start of the event the auxiliary boiler was brought on-line, reestablishing condenser vacuum. Following that, maintenance successfully closed the stuck-open main steam safety valve, steam generator B was refilled and the event terminated.

The remaining description of key points is provided below.

Feedwater Control System

In 1995, the licensee implemented a design modification to the feedwater control system which allowed for the continued operation of the reactor in the event that one of the feedwater pumps tripped. The two feedwater pumps at plant C-1 are steam driven. There is a crossover valve in the system which is normally closed. Under normal operation, above 50% reactor power, the crossover valve is closed and the two loops are split. In the event that a feedwater pump trips with the reactor at greater than 50% power, the integrated control system opens the crossover valve and reduces reactor power so that one pump can supply both steam generators without tripping the reactor.

With the feedwater pumps operating with the reactor above 50% reactor power, the feedwater control system positions the feedwater pump turbine governor valves in response to an integrated control system demand speed signal. This signal is supplied by the integrated control system in response to system demands (automatic mode), or by the control room (manual mode). The other mode of operation is the diagnostic manual mode. This mode was designed to allow the feedwater control system to determine if the integrated control system's signals were valid, or if they were invalid and caused as the result of a malfunction or failure. The feedwater control system samples the integrated control system's signal sixty times a second and determines if the signal changes at a rate greater than 30% per second. If the signal changes greater than that rate the feedwater control system transitions into the diagnostic manual mode.

Under normal operating conditions, the integrated control system demand signal drives the feedwater control system. The speed and correspondingly the output of the feedwater pumps are controlled by a governor which in turn is positioned by the amount of control oil the control oil valve lets through.

During the May 19th event, the feedwater control transient was initiated by reduced voltage to the MFW pump A control oil system 24 volt power supply bus due to a short circuit. This resulted in a decrease in control oil pressure and a corresponding decrease in pump speed. The cause of the short circuit has yet to be determined.

As a result of the decrease in feedwater pump A output, the integrated control system demand signal increased rapidly to the maximum value for feedwater pump B. Due to this rapid increase in demand, coupled with signal noise inherent to the integrated control system at the extremes of the signal range, the feedwater control system interpreted the signal as failed and transferred to the diagnostic manual mode. This resulted in the pump operating in response to its last valid demand signal which was high demand. The reactor then tripped on high pressure and the integrated control system sent a rapid feedwater reduction signal to the feedwater control system. This resulted in the closure of the feedwater block valves and intended for feedwater pump B to decrease output. However, since the pump was in the diagnostic manual mode, it did not respond. This resulted in the pump tripping on high pressure.

At this point the reactor and feedwater pump B had tripped. This left feedwater pump A to supply feedwater to the steam generators. Since feedwater pump A was below its minimum speed, it did not respond to the rapid feedwater reduction, as per design. When its fault cleared, it responded to what it interpreted as the last valid demand signal, which was high demand, instead of the correct signal which was a rapid decrease in feedwater. This resulted in feedwater pump A tripping on mechanical overspeed.

Main Steam Safety Valves

Following the loss of feedwater, the main steam safety valves on the B steam header opened to relieve reactor pressure. After sufficiently relieving reactor pressure, one of the valves failed to reseat, resulting in the isolation of the B steam generator.

The main steam safety valves are designed to provide overpressure protection for the steam generators. In this event, one of the valves failed to reseat because its locking device cotter pin was not engaged with the release nut, causing the release nut to travel down the spindle and prevent reseating. The failure was attributed to the release nut not having been properly pinned in place.

The procedure which governs the steam safety valve test in which the cotter pin is installed does call for second verification of proper installation of the cotter pin. However, the step in the procedure which directs maintenance personnel to perform the verification focused on achieving a clearance of 1/16 inches to 1/8 inches between the release nut and the top lever. Therefore, maintenance personnel believed verification was accomplished by achieving the cited clearance. However, this is not true. Achieving proper clearance and verifying proper installation are not the same.

Atmospheric Dump Valves

After the condenser was lost as a decay heat removal path, operators utilized the atmospheric dump valves. Although the valves were designed to operate automatically, operators were unable to automatically control them due to previously identified thermal binding. The thermal binding problem was not new. The plant had tried numerous corrective actions to fix the problem. Since the licensee knew the problem had not been fixed, it trained its operators in an alternate method of steam pressure control. This proved to be extremely fortuitous because had the operators not trained in this alternate method, they might not have been able to secure the plant.

Start-Up Boiler

The start-up boiler was supposed to supply gland sealing steam to the condenser in the event that normal gland sealing steam was lost. Problems with the start-up boiler were prevalent since its initial installation and included improper air and fuel mix, improper steaming rate, and improper settings in the C-38 control console and associated boiler distribution control system. These problems necessitated operation in manual mode with close operator supervision.

Step 2: Identification of Hardware Contributors and Operator Contributions

The hardware contributors are the malfunction of the feedwater control system, the stuck-open main steam safety valve, the atmospheric dump valves failing to operate in automatic mode, and the start-up boiler failing to initially provide the condenser with gland sealing steam. There are no detrimental operator contributions to this incident.

Step 3: Classification of Event Constituents as Pre-Initiating or Post-Initiating

Although many of the hardware contributors occurred after the initiating event (namely the feedwater control system malfunction), they are all pre-initiating because the reasons why they failed to perform as expected all took place before the initiating event. The operators' recovery actions are post-initiator.

Step 4: Identification and Analysis of Human Contributions to Hardware Contributors

Malfunction of the Feedwater Control System

It is not clear what the human contributions are to the malfunction of the feedwater control system. The integrated control system functioned as designed, however, due to minor electronic noise, which exists at the extremes of the signal ranges, the feedwater control system interpreted the integrated control system's signals as invalid. This type of failure is primarily a design error, with some equipment problems related to interpreting the combination of the signal plus and the noise as an invalid signal. We are not certain that this type of error could have been prevented. It most certainly can be corrected, but may not have been foreseeable. It is precisely for these reasons that the plant personnel did not detect this failure mechanism during post-modification testing of the feedwater control system.

Therefore, the work process most closely associated with this failure is the facility modification work process, in the corrective action program, in the tasks of design and post-modification testing. Organizational factors in both tasks are technical knowledge and problem identification in regards to the signal noise and its impact on the system.

Stuck-Open Main Steam Safety Valve

The human contributions to the main steam safety valve failure center around the performance of maintenance activities on the valve and in the writing of procedures used in those maintenance activities. The work processes involved with the failure are procedure writing and maintenance, specifically in the task of execution. Both are in the corrective action program. The maintenance personnel exhibited a deficiency in roles and responsibilities by not following the procedures explicitly. Additionally, they demonstrated poor technical knowledge in regards to the functioning of the cotter pin and its relationship with the release nut. The error in the procedure writing was due to poor communication in that the writer of the procedure did not effectively make known the need to ensure proper cotter pin engagement with the release nut.

In addition to the problems mentioned above, inadequate operating experience was cited in the NRC report as a precursor to this event. The NRC report claimed that the plant personnel had several opportunities to detect this fault, but did not. The report cited events involving steam safety valves failing to reseat due to cotter pin not being engaged with the release nut. However, the plant required their maintenance personnel to verify that the cotter pin was properly engaged with the release nut. Although the procedure was weak, it was not inadequate and did not reflect poor use of industry operating experience.

Atmospheric Dump Valves

The problem with the atmospheric dump valves suggests a problem with either the condition reporting work process, specifically in the prioritization of work, in the root cause analysis work process, specifically in problem determination, or in the corrective maintenance work process, specifically in work execution. All are in the corrective action program. It indicates a problem with the condition reporting work process because the licensee may have put too low a priority on addressing these concerns. This would be a fallible decision. However, the licensee may have put the proper priority on the matter and just could not identify the problem correctly. This suggests a problem in the root-cause analysis work process. Still yet, the thermal binding concerns may indicate a problem with the corrective maintenance work process because the licensee may have placed the proper priority on the problem and identified the problem correctly, but just did not implement the solution correctly. It is difficult to know what type of failure this is without more information.

Since information on which work process and which organizational factors were involved in the failure of the atmospheric dump valves to operate in automatic mode are not available, we are forced to present our best estimate. We believe that the most likely reason for the continuing problems was the low prioritization in the condition reporting work process. The problems with the atmospheric dump valves were long standing. Had the licensee decided to put the full resources of the organization into resolving this problem, the problem most surely would have been fixed. However, the people responsible for prioritization decided that the lowest priority should be assigned to this concern. This represents a fallible decision in the prioritization task of the condition reporting work process. The organizational factors suggested are goal prioritization and technical knowledge. Goal prioritization for obvious reasons, and technical knowledge because the people responsible for prioritizing may not have recognized the importance of this problem.

Start-Up Boiler

The work processes involved in the problems associated with the start-up boiler are any or all of the following. Condition reporting work process, in that these problems were not given a high enough priority, root cause analysis work process, specifically in problem determination, or in the corrective maintenance work process, specifically in execution. The reasons are the same as above for thermal binding. Again due to the lack of information available regarding organizational factors and work processes, the actual cause for the start-up boiler problems not being adequately rectified is not known. Our best estimate is again low prioritization in the condition reporting work process.

Step 5: Output

This incident began with a short circuit in the feedwater control system primarily due to technical and design issues. Although the system compensated for the loss of feedwater, the plant was challenged as a result of the problems encountered during recovery. No equipment was severely damaged and no personnel were injured as a result of this incident, however, the potential for a serious incident was present. Had the operators not acted flawlessly, or had another system been defeated, the system might not have recovered.

What were the managerial & Organizational Deficiencies?

- Technical Knowledge: In the corrective action program, in the facility modification work process, during the development task.
- Problem Identification: In the corrective action program, in the maintenance work process, in the task of execution (post-modification testing)
- Formalization: In the corrective action program, in the procedure writing work process, in the task of preparation.
- Roles and Responsibilities: In the corrective action program, in the maintenance work process, in the task of execution.
- Goal prioritization/technical knowledge: In the corrective action program, in the condition reporting work process, in the task of prioritization.

What were the dominant contributors?

The dominant contributors to this incident are goal prioritization and/or technical knowledge in the task of prioritization in the condition reporting work process, formalization in the procedure writing work process, and roles and responsibilities in the task of execution in the maintenance work process. The reason that these organizational factors are dominant contributors is that they transformed a simple transient into a much more complex one which presented a serious threat to the plant safety.

What were the consequences?

The consequences of this incident were that the plant was shut down for over a week and there was greatly increased regulatory attention.

Discussion

After identifying the task of the work process where an unsafe act occurred, by following that work processes back to its initiation, an investigator can identify which factors contributed to an incident. In addition to uncovering factors within the same work process where the unsafe act occurred, investigators can identify factors within other work processes as well. Subsequent to the identification of several factors, an investigator can use the methodology to identify specific instances in which organizational deficiencies facilitated their occurrences. The result is a more complete picture of how organizational deficiencies within specific tasks contributed to an incident. Using this information, the plant is in a better position to develop corrective actions to address these deficiencies and preclude them from contributing to incidents in the future.

COMMON-CAUSE FAILURES

Although organizational factors are recognized as being pervasive throughout the organization, up until now there has not been a systematic methodology, such as the one presented, which captures their effects on performance. Consequently, data on organizational factors' influences on failures and organizational factors responsible for common-cause failures are not available. Despite the fact that the potential for organizational factors to lead to common-cause failures is strongly suspected (Davudian, Wu, and Apostolakis, 1994a; Sewell, Khatib-Rahbar, and Erikson, 1999), the tools have not yet existed to highlight such a relationship. However, this does not mean that such a connection does not exist.

Consider the example of Plant C-1 presented above. Focusing on the two largest complicating factors in the incident, namely the problems with the start-up boiler and the atmospheric dump valve, one notices that the dominant contributor to each was poor prioritization. This prioritization, in turn, occurred in the same program, work process, and task, and was due to the same organizational factor. Although we cannot demonstrate this conclusively due to the aforementioned lack of information, we can state that it warrants increased attention.

In this example, two different systems were disabled as a result of the same reason, poor prioritization. If a low-probability plant challenge presents itself and two or more dissimilar safety systems are disabled due to a single organizational factor, the result may be a serious event. On the flip side, if we identify how organizational factors manifest into multiple failures, the identification and resolution of organizational deficiencies could serve to increase plant performance by eliminating failures previously thought to be uncoupled.

CONCLUSIONS

Although only one example has been presented, this methodology has been applied to several events. The results of the analyses have identified several instances of organizational deficiencies contributing to incidents in which plant performance was challenged. In addition to observing the same organizational factors contributing to numerous incidents, we found that certain organizational factors, although pervasive throughout the organization, have a much greater influence on the successful outcome of particular tasks, rather than being equally important to all tasks. For example, goal prioritization is generally more important to the successful outcome of prioritization tasks, whereas formalization and roles and responsibilities are more important for execution tasks. Certain factors, technical knowledge and communication, are important for the successful outcome of most tasks.

Consequently, we believe that organizational factors should not be considered separately from the tasks of the work processes where they have the greatest influence. Identifying organizational deficiencies in isolation from the unsafe acts to which they contribute is not as beneficial to plants as delineating the path from the deficiency to the incident, via the unsafe act. In order to accomplish this, since plants rely on work processes to conduct activities, the work processes must be an integral part of the investigation.

Having the six organizational factors and the context within which they occur as a guide, an investigator can more easily identify organizational deficiencies within an organization using the incident investigation methodology. We hope that by identifying and resolving organizational deficiencies, the plant will commit fewer errors resulting in fewer occurrences of complicating factors. With fewer occurrences of complicating factors, we expect operator reliability to improve. The end result will be an increase in plant performance.

Acknowledgement

This work would not have been possible without funding from the University Research Consortium, a joint venture between the Idaho National Engineering and Environmental Laboratory and MIT. We thank Kevin Burns, David Gertman, and Tica Valdes for their help.

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CHAPTER NINE
Lessons on Safety Culture: A Review of Industrial Safety on Japan

ISAO KURODA

This chapter reviews the promotion of industrial safety in Japan since 1928 and maintains that the improvement of the industrial safety level since 1970 can be traced to a specific Japanese safety culture. From the viewpoint of human factors in a broad sense, the safety promotion process was established in petrochemical plants, commercial aviation, nuclear power plants, and robot introduction in factories. In these fields, team- and organization-related human factors, as well as individual human factors, played an important role in promoting industrial safety. To achieve a safety culture, the characteristics of a particular country's history, society, religion, and customs must be carefully considered. The terrible criticality accident that occurred in a uranium processing plant in 1999 in Tokai-mura, Japan, is also discussed in this chapter. This accident raised doubts and anxiety throughout the world about Japanese safety culture.

HISTORY OF INDUSTRIAL SAFETY IN JAPAN

The National Safety Week in Japan was introduced in 1928 for the purpose of "promoting the independent industrial accident prevention activities circles, and enhancing the safety consciousness of the people in general and also establishing safety activities among them" (Japan Industrial Safety and Health Association, 1988, p. 4). During World War II, however, these safety plans were almost relinquished because military production had the highest priority in Japan at the time. The first 10 years after World War II were a survival stage for the Japanese, who were working so hard for economic reconstruction that the efforts led to over 6,000 fatalities caused by industrial accidents.

The first gas-cooled nuclear reactor began operations in Tokai in 1966. From 1970, industrial accidents such as fires, explosions, and leakage of petroleum and toxic materials started to increase at many petrochemical complexes. In 1974 these accidents reached a peak of 103 events. Then, during the latter half of the 1970s, all companies had to face the rationalization of production processes and cutbacks in manpower in order to survive the worldwide oil crisis.

The Industrial Safety and Health Law was enacted in 1972. After enactment of this law, accident fatalities promptly decreased from over 6,000 to 3,300. The reasons for this remarkable decrease in accidents seem to be the great economic impact of the 1973 oil crisis as well as an obligation for companies to improve the work environment through labor safety measures and additional energy resources for the plant.

In 1998 the frequency rate of the number of workers who needed more than a four-day rest divided by one million working hours was 1.75. The severity rate of lost days divided by 1,000 working hours was 0.16. The number of fatalities, however, still came to 2,078. Between 1975–1985, electronics engineering and mechanical engineering developed rapidly, and after the mid-1970s, problems were being solved through factory automation and robot introduction.

The International Human Robot Symposium entitled “Contribution of Microelectronics to the Enhancement of Human Life” was held in Osaka in 1982 and drew a large number of participants from European countries, the United States, and other countries. In 1982, 62.6% of all robots in the world were operating in Japan, whereas 19.1% were operating in the United States and Canada and 18.3% in Europe.

Discussions at the symposium centered on the following questions: Why are over 60% of the robots in the world used in Japan, why is each robot named after an idol and treated as if it were a colleague, and why are the robots not being destroyed by workers who fear that the robots will take away their jobs (which was the case in the United Kingdom)?

Argument was heated on the comparison of cultural and religious differences between Japan and other countries. Labor is considered to be an atonement for sin in Christian countries. In Japan, however, labor is considered to be the way to approach Buddha or God; hence, a Japanese worker views the robot as a close cooperator, not as an enemy that will take away his job. Basically, the Japanese are polytheistic, and even a robot can become an object of faith.

COMPARATIVE STUDY OF JAPANESE AND U.S. NUCLEAR POWER PLANT MAINTENANCE

The U.S. Nuclear Regulatory Commission contracted the Battelle Human Affairs Research Center to make a comparative analysis of Japanese and U.S. nuclear power plant maintenance. The researchers surveyed several Japanese plants and talked with plant operators and human factor specialists. The conclusions of this study (Boegel, Chockie, Huenefeld, Morgenstern and Olson, 1985) were:

1 Japanese reactors experienced significantly fewer trips than U.S. reactors.
2 Japanese reactors had a mean time between event for automatic scrams that was approximately 10 times greater than that of their U.S. counterparts.
3 U.S. plants had a significantly higher rate of repetitive trips than their Japanese counterparts.
4 The average availability of U.S. plants decreased steadily from 1981 to 1983, whereas Japanese plant availability increased over the same period.
5 In Japan emphasis is placed on extensive preventive maintenance of both safety-related and balance-of-plant equipment.
6 The Japanese maintenance program is based on a legal requirement to conduct an annual inspection of every nuclear power plant.
7 The Japanese have established a structured, industry-wide program of preventive maintenance that consists of four fundamental elements: (a) a statutory annual inspection; (b) a voluntary internal inspection; (c) special work, including back-fitting and corrective maintenance; and (d) routine inspection.
8 The Ministry of International Trade and Industry involves itself to a great extent in the preventive maintenance program by observing a significant number of maintenance activities during each plant's annual outage.
9 The central role of nuclear power in the Japanese plan for energy self-sufficiency greatly influences Japan's regulatory structure.
10 The group orientation of Japanese society plays an important role in determining the form and practice of management and rganizational structure within the nuclear industry.
11 Maintenance in Japanese plants is often performed by teams of workers who are cross-trained so that jobs can be rotated.
12 The group orientation of Japanese society in combination with the Japanese system of labor relations contributes to the way maintenance activities are structured and carried out.
13 During scheduled outages, most of the work is conducted either by personnel supplied by the vendors or by a subcontractor organization.
14 The Japanese nuclear industry is characterised by close, stable relationships between the utilities, vendors, and subcontractors.

OECD WORKSHOP ON CHEMICAL PLANT SAFETY IN JAPAN

As mentioned above, many chemical plants in Japan had accidents in the latter half of the 1970s. The government and companies made efforts to improve safety operations, and accidents at chemical and petroleum plants then decreased markedly until the end of the 1980s.

In 1991 the Organization for Economic Co-operation and Development (OECD) held a workshop in Japan entitled "On the Prevention of Accidents Involving Hazardous Substances." The main theme of this workshop was the role of human factors in plant theme of this workshop was the role of human factors in plant operations. Participants at the meeting discussed individual approaches to safety management, safety culture, and how the safety of chemical plants in Japan could be improved. The following final conclusions were presented at the workshop:

1 A safety-oriented company culture is key to successful accident prevention.
2 Top management should make safety-oriented policies an explicit and integral part of management policies.
3 Day-to-day safety management is the responsibility of the line manager.
4 Workers need to take active participation in the development and review of safety programs.
5 Safety precautions and preventive activities should be built in at the earliest conceptual and design stages, with importance attached to minor incidents and near misses as well.
6 Importance should be attached to the education and resources of workers, both in on-the-job and off-the-job training.

CULTURAL INFLUENCE ON INDUSTRIAL SAFETY

A mental and social climate that supports the acceptance of robots still exists among Japanese workers. From a historical viewpoint, when aspects of different foreign cultures were introduced into Japanese society, they were positively accepted, rather than opposed, and then refined to an artistic level. Industrial employees strongly identify with their company and behave in a way that shows that human relationships in a group are regarded as most important. In fact, labor unions could be called company unions. Japanese industrial employees are highly educated and very diligent. Such a mental climate has helped refine the Quality Control Techniques imported from the United States into the Total Quality Control Techniques specific to Japan; it also promotes an introduction of robots into industries that is free from employee resistance. Japan's high level of industrial safety is also attributed to this mental climate.

On the other hand, Japanese workers have high, sometimes excessively high, self-respect with regard to their engineering knowledge and technical skills, and they loathe having their mistakes or faults criticized by colleagues. To lose face is the greatest shame for a Japanese worker. This "shame culture" in Japan is working as an impediment to the straightforward reporting of human errors and incidents by workers and to the frank acceptance of such events by administrators. Such candid behavior could be one of the most important factors for preventing future accidents. Stress related to time pressures, excessive responsibility, and too-intimate human relationships are also among the biggest causes of industrial accidents.

SAFETY PROBLEMS IN THE 1970s AND 1980s

During the 1970s and 1980s huge technological systems broke down in inconceivable ways, causing serious damage and a large number of fatalities. Examples are the aircraft collision on a Canary Island runway in 1977, the Three Miles Island nuclear power plant accident in 1979, an accident in 1984 at a chemical plant in Bhopal, India, the Japan Airlines airplane crash in 1985, the space shuttle Challenger accident in 1986, and the Chernobyl nuclear power plant accident in 1986. People all over the world began to have serious doubts about the safety and reliability of large technological systems.

Investigations of these accidents revealed that they were caused more or less by a chain of wide-ranging human factors including operators; designers; manufacturers; and operation, maintenance, management, administration, and regulatory bodies. Human factors pertaining to safety issues have common characteristics in all types of industry; it is therefore very important to review the safety experiences of other industries in order to promote a safety culture.

Safety statistics of worldwide commercial aviation showed remarkable improvement from 1960 to 1975, once the use of jet aircraft was introduced. These statistics recently reached a plateau. About 20 major accidents have occurred every year, despite the development of highly automated aircraft. There are also differences based on the particular region or company. Of accident causes, 75% are attributed to the human factors of the flight crews. However, Qantas Airways has been using the same manuals to operate the same types of aircraft and has had no fatal accidents since 1951 (Airplane Safety Engineering, Boeing Commercial Airplane Group, 1997).

After the collapse of the USSR in 1990, 286 small airline companies rushed to compete under the new deregulation. But many of these domestic airlines had accidents because of the increased workload, fuel deficiency, inappropriate skills, inadequate parts, and over-aged aircraft (Lenorovitz & Rybak, 1994).

DIFFERENCES BETWEEN SAFE AND UNSAFE ORGANIZATIONS

What are the differences between organizations that have accidents and those that do not, given that both use the same type of equipment and operating procedures? In order to address this question, the International Nuclear Safety Advisory Group of the IAEA had several meetings on safety culture after the Chernobyl nuclear power plant accident. Safety culture was defined by this group as follows (International Atomic Energy Agency, 1991, p. 1): "Safety culture is an assembly of characteristics and attitudes on organization and individuals which establishes that, as an overriding priority, nuclear plant safety issues receive the attention warranted by their significance."

Safety organizations give top priority to safety, rather than production, and base the company's safety policy on the concept of its responsibility to society. They put this policy into practice throughout the organization, from top management down to the field workers. The managers and workers actively participate in the development and review of safety programs, and they take responsibility for safety on their own initiative, without depending on outsiders.

Such an organization encourages line managers to have an open attitude that accepts incident reports frankly; it also sets up a dynamic system to cope immediately with any dangerous situation. The specialists who were trained to and can monitor the whole company system are authorized to promote safety-related work. As mentioned above, the establishment of a safety policy, a flexible and robust system design, and appropriate activities are essential for the promotion of a safety culture.

RECENT PROBLEMS RELATED TO INDUSTRIAL SAFETY

Times pass quickly and bring with them various cultural evolutions. A new generation is developed almost every 10 years. Accordingly, the mental and safety culture within industries is changing in Japan. Many new safety problems must be faced, such as complacency toward automation and robots, loss of situation awareness, difficulties with maintaining operators' skills, the boredom-panic syndrome during emergency situations, low comprehension of the system among employees, and deterioration of work morale.

On September 30, 1999, an unbelievable criticality accident occurred in JCO Company, a uranium processing plant in Tokai-mura, during the production of a uranium solution. One hundred-fifty people were exposed to the radiation. Two of the three workers who were exposed to a massive dosage of radiation died of multiple organ failures 83 and 210 days later, respectively (Sasou, Goda, & Hirotsu, 2000).

The Accident Investigation Committee for the Nuclear Safety Commission investigated the causes of the JCO criticality accident and found that not only deviation from government-authorized processing methods but also negligence of JCO's own procedures reported to the government resulted in the accident. The root cause of the accident, however, was considered to be deterioration of the safety culture, which resulted from a conflict between commercial activity interests and the safety concept. This root cause in turn arose from a lack of safety culture in Japan's nuclear fields, not only within JCO Company and the regulatory bodies but also among many nuclear engineers who did not predict such a criticality accident and who were overconfident about safety levels. The Japanese government quickly took steps to reevaluate and rebuild the system design of nuclear safety in order to earn the people's trust in nuclear safety.

The industrial system is growing at a rapid pace, and the potential for a severe accident, like those at Chernobyl and JCO Company, looms before Japanese society. Therefore, taking the cultural changes from generation to generation into consideration, a new safety approach to dealing with the man-machine, man-system interface and safety culture must be created in this current age of automation and computers.

Over 60% of the causes of accidents in various industrial fields have been attributed for the most part to a broad category of human factors including plant procedures, work organization, managerial methods, and other human-based causes that are common to all plants regardless of their type or technology. In order to promote a safety culture, the strategy for a new approach to human factors related to automation and the new information society should include not only individual factors but also team and management factors, with consideration given to social and religious behaviors as well.

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CHAPTER TEN
Assessing the Influence of Organizational Factors on Nuclear Safety

BJÖRN WAHLSTRÖM

The importance of organizational factors in the causal mechanisms of human errors and in the control of recovery in nuclear safety has been recognized by many organizations around the world. Despite this recognition, there are as yet very few methods for systematically assessing and improving organizational factors. The majority of research efforts applied so far have tended to be modest and scattered. This chapter builds on various projects at VTT Automation, which is one of the nine research institutes of the Technical Research Centre of Finland (VTT). A preliminary framework is presented which describes how various organizational aspects may influence nuclear safety. This framework is thought to provide a kind of metamodel to be used for defining methods and tools for assessing safety and organizational efficiency. Ideally, the framework should support the definition of safety indicators, the construction of organizational surveys, the implementation of self-assessment methods, and so on. Some thoughts on how to continue this research are provided in the conclusion.

It is widely recognized today that the safe and reliable operation of nuclear power plants depends not only on technical excellence but also on individuals and the organization. Unfortunately, there are far fewer models and methods for assessing the influence of human and organizational systems on safety than there are for assessing the influence of technical systems. Safety management must build on a thorough understanding of the interactions between technical and organizational performance in order to be efficient. Investigations of incidents and accidents clearly demonstrate the importance of organizational factors as initiators of events and as factors that can make the consequences of events worse.

Since the use of nuclear power for the generation of electric power, the nuclear power industry has experienced two devastating accidents. Both accidents initiated a thorough reevaluation of contributors to nuclear safety.

The first accident was in 1979 in the United States at the TMI-2 plant near Harrisburg, Pennsylvania, and demonstrated the importance of the human factor to the whole nuclear community. A contributing factor to the second accident in 1986 at Chernobyl Unit 4, near Pripyat in the Ukraine, was a deficient safety culture at the plant.

The history of nuclear power illustrates a shift of emphasis in the safety considerations from mainly technical issues to human factors and broader issues connected to organization and management. This shift can also be seen in international interest in the concept of safety culture and the assessment of safety culture through peer reviews. Of course, the risk of accidents cannot be removed from nuclear power operations, but today there is an increased recognition among nuclear power plant operators that the economic risk connected to extended outages can be equally important to address.

The concepts of organizational factors and safety culture are closely linked, and the methods proposed for their assessment have much in common (see Wilpert, in this volume). Unfortunately, neither of these concepts is directly applicable to operational safety management at nuclear power plants. Various efforts have been made to bring the concepts closer to the normal day-to-day activities at nuclear power plants, but there is still considerable confusion even in the definition of the concepts.

This chapter reviews some ideas and findings connected to organizational factors and safety culture from recent and ongoing projects at VTT Automation. In particular, the project "Organisational Factors: Their Definition and Influence on Nuclear Safety" (or "ORFA"), funded by the Nuclear Fission Safety Programme of the Commission of the European Communities, has been very influential (Baumont et al., 2000).

A CHANGED ENVIRONMENT

The nuclear power plants of today operate in an environment that has changed dramatically over the last 25 years. In the 1970s, nuclear utilities were large state-or municipality-owned companies that were able to recover their costs through electricity tariffs. Today, the deregulation of the electricity supply has forced electricity producers to respond to signals from a competitive market. The increased competition has also forced nuclear utilities to become cost-efficient. Where technical excellence was the driving force for many nuclear utilities in the past, today nuclear utilities are more often governed by concepts such as rightsizing, return on investments, and shareholder values. Structural changes throughout the industry, brought on through acquisitions and mergers, also necessitate bringing together different company cultures.

The changes brought on by deregulation have triggered an increasing pace of change in nuclear power plant operations. In search of efficiency and cost reductions, nuclear power plant operators have applied concepts and methods from business management in the market-driven industries, but this strategy brings its own dangers. The process of carrying out cost reductions entails a risk that crucial competencies will disappear, bringing on devastating consequences. Sound succession planning and the maintenance of organizational memory are also problematic at present, for the recruitment of young people has become increasingly difficult. These changes are further aggravated by aging plants and obsolete Instrumentation & Control systems, which force nuclear power plants to modernize even though the scarcity of resources and personnel make it difficult to manage such projects.

The regulatory climate of nuclear power has also changed. In the pioneering days of nuclear power, regulation was created almost in parallel with plant concepts. Today there is a well-established regulatory framework, and regulation requires continuous investments in safety improvements. Early regulation was technical in its content, but today regulators also stress the quality of work in various safety-related work processes. Requirements concerning human and organizational factors are also coming under regulation. Changes in the regulatory framework have increased the burden of proof for nuclear power plants in demonstrating continuing safety. International cooperation has brought some harmonization into national regulation and safety practices, but there are still considerable differences in regulatory approaches.

The largest problem, with which the entire nuclear community is struggling worldwide, is the waning societal support for nuclear power. During its early phases nuclear technology was seen as very advanced, but now media coverage often connects nuclear power with images of backwardness and danger. In some countries, the societal support of earlier times has now declined to such an extent that even societal disobedience is tolerated as a way of expressing opposition to nuclear power.

REQUIREMENTS FOR ASSESSING ORGANIZATIONAL PERFORMANCE

Practices for safety management have improved considerably over the years. The primary force behind this improvement has been a systematic collection and analysis of operational experience. This pool of knowledge has been efficiently shared between nuclear power plant operators all over the world through the efforts of international organizations such as the International Atomic Energy Agency (IAEA), the World Association of Nuclear Operators (WANO), and the Organisation for Economic Co-operation and Development/ Nuclear Energy Agency (OECD/NEA). The difficulty, however, is that in periods of rapid change, learning through experience may not be efficient enough to avoid safety-related incidents. It has actually been argued that rapid societal changes combined with increased pressure for cost-effectiveness may create situations in which organizations have a high tendency to failure (see Rasmussen, in this volume).

The organization of a nuclear power plant can be seen as analogous to a control system, which ensures that activities and work processes are carried out efficiently and satisfactorily. This control system is implemented by people and through people, which means that it is both self-structuring and adaptive. When this control system functions as intended, the nuclear power plant can be operated safely over prolonged periods. An organization, like any other control system, relies on continuous feedback on performance at several levels in order to initiate corrective actions when problems are detected. An assessment that provides feedback on organizational performance in its entirety can be seen as one way of closing the loop.

An organizational assessment requires a norm so that comparisons can be made. What are the characteristics of organizational excellence, which organizational structure is optimal, and how can deficient performance be detected? Unfortunately, there are no generally accepted norms by which the performance of a nuclear power plant organization can be assessed. Various models and methods have been suggested, but they are mostly based on assumptions, limited experience, and expert opinions. Another problem is that any assessment will be subjective when both the assessors and the assessed have stakes in the outcome.

In building models and methods for organizational assessments, one has to have a good understanding of how an organization functions. This prerequisite includes an understanding of how sometimes subtle influences can, through avalanche effects, simultaneously undermine several safety precautions. The models also must include a description of the processes and activities by which safety is ensured at a nuclear power plant. The rapid changes taking place in the nuclear power industry make it increasingly important to bring in proactive organizational planning together with feedback on experience. Unfortunately, there are very few, if any, methods available for assessing the safety impacts of organizational changes.

CONCEPTS, ACTIVITIES, AND PROCESSES IN BUILDING SAFETY

Goals and requirements set the scene of all activities in an organization. Goals and requirements are in part provided from the outside and in part defined within the organization. An organization responds to goals and requirements through a process of planning and execution. In this process various tools and methods are used to achieve the required work quality. Finally, the collection and analysis of operational experience provides feedback for further refinements in control processes.

The concepts of authority and responsibility are important in considering the tasks people do within an organization. A common requirement in high reliability organizations is that a clear line of authority and responsibility should be in place by means of which everyone has a superior to whom he or she reports. The line organization is typically represented through an organizational chart. Assumptions about authority and responsibility are written into organizational handbooks, but they are also implicit in procedures and practices.

A few basic activities can be used to break up tasks into smaller parts. One set of such activities is to manage, construct, operate, maintain, verify, and analyze. These activities can influence the technical systems for resources used by the organization. In a discussion of resources the following types may be distinguished: financial, human, information, tools, methods, space, and time. Activities are connected to larger entities, which together form the work processes within safety management (Rollenhagen, 1999).

Work processes are sometimes considered to be complementary to the line organization. Work processes give a horizontal view and the line organization a vertical view of the organization. Of course, when considering work processes at a nuclear power plant, one can define and structure them in many different ways. Some work processes are directly connected to the nuclear power plant itself and others to creating and maintaining resources used by the main processes. Often, models of the work processes need to be built in order to be able to assess how they interact. Formal tools have been developed for this purpose.

Many attempts have been made to identify and define issues connected to organization and management that are important for nuclear safety. One recent report identified 12 organizational factors that should be considered in an assessment of safety management practices (OECD/NEA Committee on the Safety of Nuclear Installations, 1999). In spite of general agreement on the importance of organizational factors, there is unfortunately no consensus on their definition or relationships. A general categorization of relevant variables connected to organizational factors important for nuclear safety is provided in Figure 10.1 (Wilpert, Miller, & Wahlström, 1999).

DIFFICULTIES CONNECTED TO DECISION-MAKING IN NUCLEAR POWER PLANT ORGANIZATIONS

There are many similarities between organizations in general and organizations managing nuclear power plants, but there are also important differences. The most important difference is the very high safety requirement, which is due to the fact that the reactor requires continuous attention and that failures in this regard can lead to serious hazards. Experience has also shown that an incident anywhere in the world has an influence on the industry everywhere. The dilemma in this situation is that

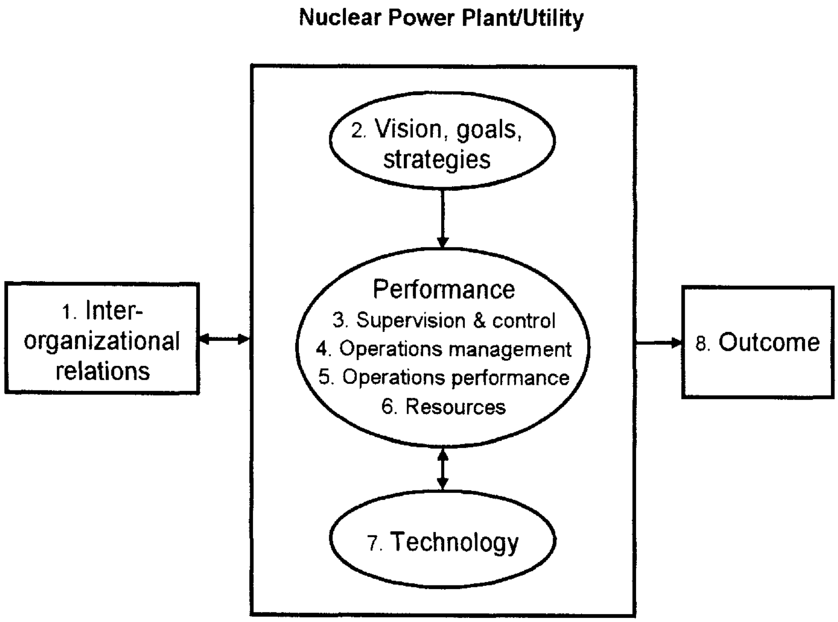

Figure 10.1 Organizational factors and nuclear safety: a categorization of relevant variables. From *Report on Needs and Methods* (Report No. AMM-ORFA(99)-R03) by B.Wilpert, R.Miller, and B.Wahlström, May 1999.

essentially no errors are allowed, yet the business risk is still connected to the worst performers in the whole industry.

A nuclear power plant is a very complex system, which for its operation demands high skills in several disciplines. The complexity of the interaction between various technical systems on the one hand and between the technical systems and the human and organizational systems on the other makes it very difficult to predict in detail how a nuclear power plant will perform in a specific situation. Management of the knowledge needed both in nuclear power plant operations and in the industry in general therefore becomes a very challenging task, especially when many young persons do not feel attracted to a career in the nuclear power industry.

Operational experience has shown that it is difficult to maintain the vigilance needed for continuous attainment of safety. There have also been examples where difficulties in managing the transition from design and construction to operation and maintenance have led to problems (Andognini, 1999). One may even advance the observation that past success can lead to complacency within the organization, which may produce a widening gap between actual and perceived safety performance. In addition, the higher levels of management must be extremely careful not to convey a mixed message on the need to cut costs, thereby shifting the focus away from safety issues.

Hands-on operational decisions are made in the main control room. These decisions depend on information presentations and procedures, which were created by design engineers. Various disturbances require a proper functioning of safety systems, which may be impaired by hidden maintenance errors. Plant management should be alert to problems both within the technical systems and in the interaction between technical systems and people. However, for various reasons management may not get proper signals of emerging problems (see Carroll & Hatakenaka, in this volume).

Probabilistic safety analysis (PSA) is one tool for modeling interdependencies in the systems. Unfortunately, this tool is not well suited to modeling the influence of human and organizational factors. The tool can, however, give indications of event sequences, which are sensitive to human errors and thus target efforts in developing information presentation, procedures, and training. One way to use the tool for assessing organizational factors is to define the assumptions (which should be present for the PSA to provide a believable estimate of the risk) as an organizational norm. When these assumptions are made explicit it is easier to check their validity in an organizational assessment.

METHODS FOR ASSESSING ORGANIZATIONS

Organizational performance can be assessed through various methods. Some rely on an external team of assessors, but most methods can also be used for self-assessments. Data for the assessment can be collected through the use of observations, inspections, interviews, and questionnaires. Checklists are available for carrying out audits and peer reviews. One problem with many methods is that they are not theoretically grounded. This situation makes it difficult to carry out intercomparisons of results obtained through two methods. All methods must be adapted to the language and the organizational culture to which they are applied, which makes it difficult to do intercomparisons between data collected at different nuclear power plants.

As a service to their members, the IAEA and WANO have developed various schemes for carrying out peer reviews. Typically, a team of 10 to 15 international experts during a two- to three-week mission carries out the reviews, which include observations, inspections of documents, and interviews. The services provided by the IAEA include Operational Safety Review Teams (OSART: organization and management), Assessment of Safety Significant Events Teams (ASSET: incident analysis), and Assessment of Safety Culture in Organizations Teams (ASCOT: safety culture).

Most nuclear power plants have well-established practices to monitor and analyze operational events and incidents at their facilities. The goals of implementing these practices are to learn from available experience and to correct observed deficiencies in the plant and its operations. A common aim in the investigation is to identify root causes of the incident. In the analysis process it is important to search for not only the technical causes but also the human and organizational causes. In assessing organizational performance one can consider events that have been analyzed and conclusions that have been reached and thereby assess the event analysis process itself.

Performance indicators are used by some nuclear power plants to give regular feedback on performance. Such indicators can give management valuable information on the performance of the technical, human, and organizational subsystems. When work practices are compared across different nuclear power plants, performance indicators can also give valuable information on different ways of designing and conducting safety-related activities. Such benchmarking exercises can both provide a qualitative feeling for differences between two organizations and give hints for further improvements (Wahlström & Kettunen, 2000).

When making an organizational assessment it is necessary to agree on the depth of the exercise and to identify the topics to be addressed. A decision to go deeply into organizational activities may involve a great deal of effort, but a shallow study may not be able to bring the most important issues to light. Activities with a big influence on safety are always more important to investigate, but a focus on such activities may leave problems in peripheral activities unnoticed. It is sometimes necessary to involve outsiders to ensure impartiality in making interpretations and recommendations. It also may be easier to achieve openness in interviews if persons outside the organizations carry them out.

A FRAMEWORK FOR CONSIDERING ORGANIZATIONAL FACTORS

A systems approach provides a suitable basis for establishing a framework to consider organizational factors. A systems approach involves a division between the system to be investigated and its environment. It also assumes that the construction of a model of the system can aid significantly in understanding and controlling the system. The concept of a model carries the related concepts of components and their interactions. The division of a system into smaller parts also enables two views: that of the entire system and that of its details. In considering interactions between components of a system, the concept of causality is important. In the examination of human and organizational systems' components, understanding and intention are added to the usual physical causality of technical systems.

The first step in dividing the nuclear power plant system into components is to consider the four subsystems of technology, organization, groups, and individuals together with their interactions. There are also interactions

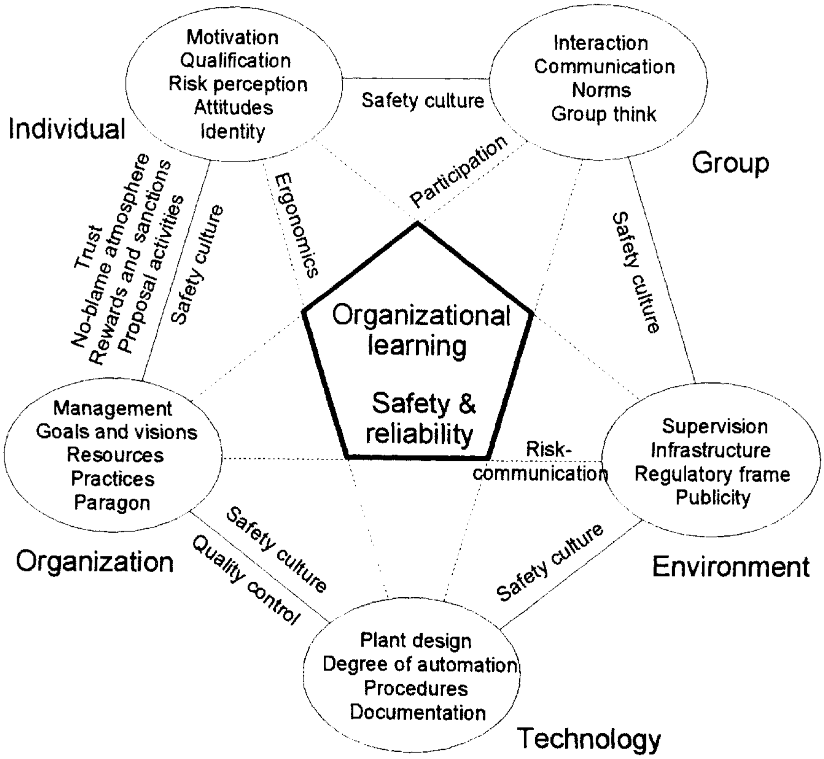

Figure 10.2 The five interacting systems of nuclear safety

between the environment and each of these subsystems. Important parts of the nuclear power plant environment are supervision, infrastructure, the regulatory framework, and publicity. Within the technology subsystem there are important parameters to be considered, such as plant design, degree of automation, procedures, and documentation. In the organization subsystem issues such as management, goals and visions, resources, practices, and best-practice examples become important. On the group level, interaction, communication, norms, and groupthink should be considered. Finally, on the individual level issues such as motivation, qualifications, risk perception, attitudes, and identity contribute to performance. In this way safety culture can be seen as a feature that penetrates all subsystems and their interactions (see Figure 10.2).

Further examination of the organizational subsystem entails many more dimensions that can be considered relevant to an assessment. The extent to which an organization has structure is an important characteristic when one assumes that a nuclear power plant organization requires some minimal

Table 10.1 Common dilemmas of efficient management

Traditions	vs	renewal
formal	vs.	informal
self-confidence	vs.	willingness to listen
co-operation	vs.	competition
centralised	vs.	distributed
discipline	vs.	flexibility
focus on details	vs.	maintaining an overview
monitoring & reporting	vs.	confidence & accountability
short term	vs.	long term optimisation
specific/practical	vs.	generic/theoretical

degree of structure. A second dimension relates to the integration of the activities and the assumption that efficiency requires some reasonable amount of integration. A third dimension is the degree of self-reflection that the organization is able to 1exercise, assuming that self-reflection is necessary for consciously proactive nuclear power plant operation.

Similar considerations that may be used in assessing organizational characteristics are qualities conveyed through the dimensions “open/closed” and “formal/informal.” The “openness” or “closedness” of an organization gives a measure of how easy it is to become a member of the organization and the extent to which it reveals its principles of operation to outsiders. Open internal communication can be assumed to be necessary to detect and correct problems, but a nuclear power plant organization must also be somewhat closed to protect its members. Similarly, the formality of an organization expresses the extent to which it relies on established procedural tasks as opposed to flexibility and ad hoc procedures. Nuclear power plants certainly depend on formalized procedures, but these procedures should not be allowed to stifle individual initiative. More generally, these dimensions can be thought of as a conceptualization of common dilemmas faced by efficient management (see Table 10.1).

Recommendations for Further Research

There is a long way to go before models and methods for the assessment of the influence of organizational factors on nuclear safety reach a stage where they can be applied routinely in operational safety management. To reach such a level, efficient communication between theory and practice must be established. Such communication must build on trust that the information disclosed by nuclear power plants is not used against their interest. If the polarization of opinions on the use of nuclear power is further increased, it may, unfortunately, be difficult to reach the required level of trust.

The nuclear power plant subsystems and organizational factors to be considered were discussed earlier in this chapter. Further research might attempt to map the interfaces between subsystems and organizational factors more accurately and investigate causal couplings between factors. To some extent this step also implies the elicitation of tacit knowledge that skillful managers use to make their experience sharable within the nuclear community. The contribution of the research community in this endeavor would be to systematize and generalize the knowledge collected.

It may even be possible to move forward by only making the consideration of organizational factors more explicit than in the past. If a discussion of organizational factors can create greater self-reflection together with an awareness of various pitfalls, the participants can improve as managers. These improvements will, however, not make various models, methods, and tools unnecessary but rather give them a place among other organizational resources in meeting the challenge of ever-increasing efficiency and safety needs.

In the short term, future research might engage in building models of organizational structure and work practices, describing good practices in a rapidly changing environment, identifying obstacles to organizational learning, developing methods for considering organizational factors in incident analysis, suggesting methods for organizational self-assessments, and comparing safety management practices. In the longer term, research could engage in the development of theoretical models of how organizational factors interact with crucial components of performance, proactive methods for organizational design, methods for the integration of organizational factors into PSA models, and an understanding of the impact of cultural influences in the safety management of plants and in the relationship between plants and regulators.

CONCLUSIONS

The consideration of organizational and management issues as contributors to nuclear safety is becoming increasingly important. One difficulty is the absence of a theoretical framework within which organizational factors and their causal relationship can be dealt with. Such a theoretical framework could also support data collection and organizational development.

A consideration of organizational factors must rely on well-grounded models. A theoretical framework can be found in psychology, sociology, and the management sciences. The problem in finding suitable models is to strike a proper balance between models that are too simple and give only trivial answers and models that are too complex to be practical. The models must be understandable for those expected to use them.

When beginning research aimed at investigating connections between organizational factors and nuclear safety, there are some pragmatic guiding principles that should be attended to. First, the efforts should address real cases of organizational change in nuclear plants or companies. Second, the data should be collected in a way that supports systematic intercomparison of important issues. Third, each case study should be summarized with an account of lessons learned in the use of methods and tools. And finally, general findings should be drawn and documented in a way that makes them accessible across national and company cultures (cf. Hofstede, 1997).

Safety is a fundamental prerequisite for the use of nuclear power. The extreme safety requirements of nuclear power generation necessitate special precautions and methods, which may not be found among those precautions and methods used in the market-driven industries. The consideration of high reliability organizations as an object for research may help in this endeavor. A fruitful combination of theory and practice is a necessary precondition for success. If these efforts succeed, nuclear power can continue to be a realistic energy option in the future.

Acknowledgement

The support for this research from the Fourth Framework Programme on Nuclear Fission Safety of the Commission of the European Communities (Contract No. ERB FI4S-CT98_0051) is gratefully acknowledged.

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CHAPTER ELEVEN

Interrelationships Between Organizational Factors and Major Safety Indicators: A Preliminary Field Study

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Most industries have been continuing intensive efforts to reduce labor injuries and facility failures caused by human performance problems. Some of these efforts should be shaped by organizational commitments, in the form of top-down or bottom-up activities. In order to make these activities effective and practical under the daily pressures of production, it is important to consider which to do and how to implement them. In this respect, this chapter describes the interrelation between organizational factors or commitments and safety performance indicators by employing a conceptual structure of organizational factors. These interrelationships are discussed based on results obtained through a preliminary survey, conducted in the construction and petrochemical industries, which adopted the labor accident rate as a safety performance indicator. In addition, several important organizational factors that influence the indicator in both industries were commonly identified.

Accidents or incidents commonly occurring in industries include both labor injuries and facility failures caused by human performance problems. Both labor injuries and facility failures are somewhat different with regard to causalities, complexity, and the scale of consequences; however, the frequency with which they occur is surely linked to workers' safety consciousness and organizational factors or commitments that promote safety environments and reduce accidents. Reason (1997) suggested that lost time injury frequency (LTIF) would not be indicative of facility failure frequency. This assertion is thought to be true in one respect, because countermeasures and reactive actions for each of them should necessitate quite different considerations. Increased efforts to improve individuals' safety consciousness and avoid violations is necessary to reduce LTIF, whereas more emphasis on detecting overall system defects is important for reducing facility failures. The differences between reducing LTIF and reducing facility failures may depend on how practitioners give weight according to the extent of their industrial hazards. Their phenotypes are different, but their genotypes derive from the same origin. The likelihood of producing original defects in barriers that will lead to facility failure does not seem to differ much from that of committing labor accidents for sharp end in the same company. Exemplary domestic companies realized and continued a low level of accident rates for both labor injuries and facility failure. One of the most basic determinants seems to be the extent to which safety culture is created and maintained within organizations. The performance of companies with excellent safety records, such as DuPont Company, Qantas Airways, and Shell Oil Company, suggests the importance of eliminating both phenotypes.

After 1980, intensive studies were conducted to investigate the relation between safety, organizational culture, and organizational climate. Zohar (1980) investigated three major industries—the food-processing, chemical, and textile industries—through the use of questionnaires and found significant organizational climates of workers' perceived importance of safety training, the perceived effects of the required work pace on safety, and the perceived status of the safety committee or safety officer. However, there was no significant regression between the accident rate and organizational climates. Diaz and Cabrera (1997) later carried out an intensive survey of airline ground staffs on the relation between staffs' safety attitudes and organizational climates. They found a significant regression of safety attitude with organizational policy on safety, an emphasis on productivity versus safety, and group concerns about safety. In the nuclear power industry, Haber, Shurberg, Barriere, and Hall (1992) began research that developed methodologies and then applied them to actual fields. They adopted several practical methods: functional analyses by means of "walk through" and "talk through," observation of employees' behavior, and questionnaires investigating employees' organizational behavior, work environments, and safety consciousness. They concluded that the following five organizational factors are essential for safety performance: communication, standardization of work, decision-making and problem-solving, management consideration and oversight, and organizational culture.

The above studies suggest that there may be no significant regression between safety performance and organizational factors. The most important finding is that there may be controllable organizational factors that promote safety culture. Reason (1997) found that companies with successful safety records also have in common top management's commitment, cognizance, and competence with regard to the safety engine. He also insisted that navigation aids, that is, a proactive and reactive information collection system on job and local hazards, can fuel the safety engine. He concluded that the subcomponents of a safety culture are: (a) a reporting culture, which provides an atmosphere and procedures that encourage workers to report their own near-miss events and human error incidents; (b) a just culture, which has systems or rules for blaming workers who commit intentional violations; (c) a flexible culture, which has organizational systems capable of adapting to changing situations through shifting organizational forms from centralized control to a decentralized mode under the daily conditions of a strong and disciplined hierarchical structure; and (d) a learning culture, which includes both workers' strong determination not to forget the lessons learned from experiences and continued efforts to improve the organization's management of controlling hazards.

The aims of this study are to find effective organizational controls to improve safety performance, especially to discover whether there are any differences in organizational controls between decreasing the reate of labor accidents and decreasing the rate of facility failures in industries. We pursued these aims by placing emphasis on various safety activities implemented by small groups, such as the typical *kaizen* (continuous improvements for work condition) proposal. Taking the above-mentioned works into consideration, this chapter initially describes a preliminary conceptual modeling of the safety performance-organizational factors structure, which was developed in order to search for relationships among organizational climate and culture, safety consciousness, safety behavior, and safety performance. Based on this conceptual model, a research plan was prepared in order to distribute questionnaires to companies so that interrelationships between labor accidents and organizational factors in the construction industry could be found; the other was for facility failures in the petrochemical industry. The questionnaires in particular looked into the effects of safety activities and safety controls within each company. Analyses of the obtained results are currently in progress; thus, only the cases adopting the labor accident rate as the safety performance indicator were introduced in both industries.

MODELING OF ORGANIZATIONAL FACTORS INFLUENCING SAFETY PERFORMANCE

The interrelation between accidents and organizational factors is complex and complicated, yet hypothetical, conceptual understandings of their structure are necessary in order to take steps toward preventing accidents. Organizational factors involve various conceptions and functions in themselves, so some simplification is essential when starting out research in this area. Taniguchi and Tomioka (1995) proposed the hypothesis of a hierarchical structure, in which the top represents safety and production performance, the second tier is workers' behavior, the third is organizational and technical management, the fourth is organizational climate, and the bottom tier is organizational culture. In addition, an organization is surrounded by social conditions. Working from this hypothesis, we first roughly classified various organizational factors and their relevance into groups (see Figure 11.1):

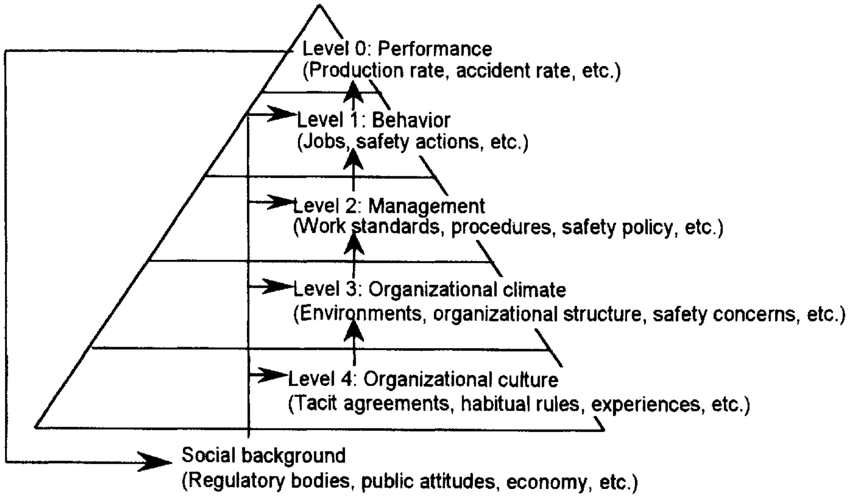

Figure 11.1 Hierarchical structure of organizational factors influencing human performance

1 Level 0 (the performance level) represents safety and production performance (e.g., LTIF, benefits, facility failure, and risk).
2 Level 1 (the behavioral level) denotes job and safety behavior.
3 Level 2 (the management level) includes safety and work standards, job and safety policy, job procedures, instruction style for the organization as a whole and within smaller groups, the consensus procedure within an organization, power centralization/decentralization, job qualifications, the role-sharing scheme, the supervision scheme, and personnel administration.
4 Level 3 (the climate level) includes the workplace environment, the structure of the organization (hierarchy, flat, or flexible), orientation toward the future, competence and motivation at the individual and organizational levels, the security and status of jobs, job automation and mechanization, and how to progress the job steps.
5 Level 4 (the cultural level) pertains to individual and organizational tastes and senses of values, tacit agreements, habitual rules and regulations, individuals' and the organization's psychological character, organizational experiences and history, the scale of capital and the number of employees, and so on.
6 Finally, the social background includes pressures from regulatory bodies, public acceptance, media coverage, the economic situation, national character, national history, regional differences, and religious issues.

The outputs of Level 0 are directly transmitted as feedback to the social background and consistently influence Levels 1 and 2. Usually, relatively less feedback affects the level of organizational climate and culture, which cannot be changed quickly (Reason, 1997). Organizational climate can be considered to be an outcome of organizational culture, although their discrimination is somewhat obscure. “Culture” is closer to concepts of the basis and fundamental core of an organization, whereas “climate” more directly affects management and behavior (Kato, 1982). Management involves administrative controls and regulations that promote the motivation and satisfaction of individuals and teams. There are two important aspects of management: One aspect entails preventive and environmental factors, which include rewards, supervision, working conditions, and cooperation with others; the second involves motivators, which include recognition of achievements, support for progress, the evaluation of work, allocation of responsibilities, and job promotion. The hierarchical structure described above does not seem to be that far off from the real world. Nevertheless, a discussion encompassing all of the factors mentioned above would be so broad in scope that it would no longer be practical. Thus, we have limited our discussion to safety issues.

Inoue (1992) and Watanabe (1996) have suggested that safety consciousness is crucial to avoid human errors and improve safety performance in the local workplace. They asserted that safety consciousness is the basis for workers’ behavior when carrying out job tasks and that it dominates not only safety behavior but also workers’ intentional safety violations. Furthermore, safety consciousness has a significant regression with organizational climate and culture. We therefore reconstructed the above hierarchy to fit the world of safety issues. Figure 11.2 shows a hierarchical structure that we developed when conceptualizing safety as the main objective. In this figure, organizational climate and culture are brought together in the same domain because their discrimination is ambiguous. Regarding organizational commitments to safety improvements, Reason (1997) indicated that it is necessary to take upstream of local workplace and sharp end into consideration. He identified five important clusters: safety-specific factors; managing factors; technical factors; training, which can be transferred relatively easier than safety consciousness (human himself); and organizational climate and culture (organizational factors that cannot be controlled directly).

The type of safety management depicted in Figure 11.2 is not equivalent to “safety-specific factors” but rather includes broader senses comprising the five clusters that can affect safety issues. Figure 11.2 shows that direct commitments can only be made to controllable organizational factors, that is, to the safety management level. We maintain that commitments to this level gradually infiltrate into the organizational culture, or the so-called safety culture, via the organizational climate. These commitments also penetrate

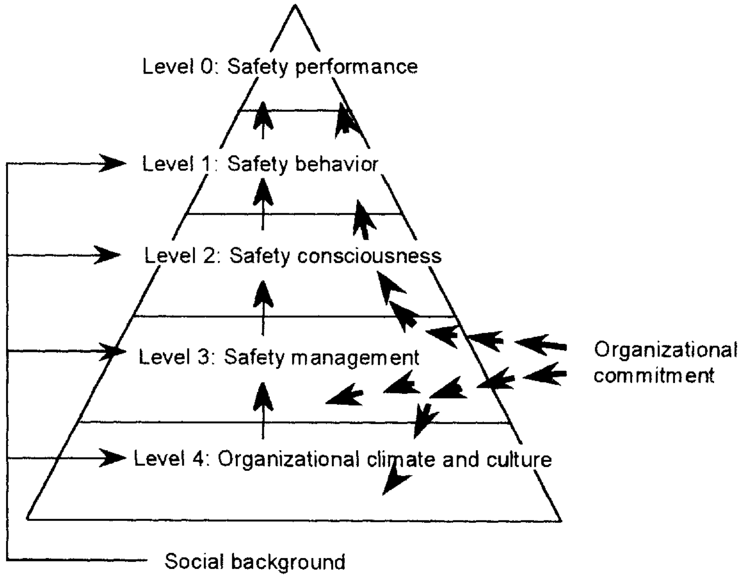

Figure 11.2 Hierarchical structure of safety performance: organizational commitments

little by little into safety consciousness and, finally, safety performance via safety behavior. Therefore, we expect that the interrelationships between layers and within each layer, shown in Figure 11.2, can be understood. We also expect that the difference between safe and unsafe organizations with regard to these interrelationships can be revealed. In addition, it is important to explore how to make effective and efficient commitments. We shall now introduce our preliminary investigation from this viewpoint.

METHODS

Investigation of Selected Industries

Considering the activities carried out in nuclear power plants, one finds that maintenance and repairs performed in the nuclear power industry share many similarities with those performed in the construction industry. This similarity arises from the nature of the jobs and the hierarchical contract structures. We therefore chose the construction industry as one object for our investigation. From another perspective, the daily operational activities and safety management practices in the petrochemical industry seem to entail almost the same hazards as the respective activities and management practices in nuclear power plant operation departments. Thus, we adopted both the construction and petrochemical industries for our preliminary survey. As a result, 37 construction companies and 29 petrochemical companies and their 176 factories were selected for this investigation.

Format of Field Survey Questionnaires

In social science, plenty of questionnaires have been proposed to study organizational structure and organizational factors. However, previous investigations have tended to focus on how to promote organizational efficiency or keep up workers' motivation. In addition, questionnaires drawing from all organizational aspects of previous studies would become too many, therefore some kind of selection of possible items relating to safety issues is inevitable.

Consequently, we emphasized safety-related issues in choosing a reasonable amount of organizational factors. For this study, several works were chosen in order to draw up a list of questionnaire items related to safety issues: We drew from questionnaires used to evaluate safety attitudes within organizations in the railway industry (Watanabe, Miyahara, Fukushima, & Suzuki, 1994; Yabuhara, 1988), manufacturing (Kato, 1982; Morita, 1984), and nuclear power plants (Haber et al., 1992; Taniguthi & Tomioka, 1995). For a survey, questionnaires evaluating organizational health and diagnosis were added. Every item obtained from these questionnaires was described on a card. These cards were then classified into groups where each card had almost the same meaning. About 100 items were then selected from the resultant groups of cards in order to reduce the burden placed on respondents. Among organizational factors, items relating to communication within an organization and factors on how to improve tasks or schedules were kept in the selection. The clusters and respective items shown in Table 11.1 were finally chosen for this study. In the end, there were a total of 134 questionnaire items, including clusters on safety performance records, the safety consciousness of fieldworkers as evaluated by safety personnel, the administrative policy and system, bottom-up safety activities, acquisition of ISO licenses, safety management, the safety section's activities and position, and organizational climate and culture.

Implementation

The investigation was conducted in cooperation with the industry federation. All questionnaires were distributed through the federation in order to raise the response rate. The questionnaire sent to the selected companies included instructions explaining that one respondent should be a safety manager working in cooperation with field supervisors. In addition, the instructions requested that a director in charge of safety at the headquarters office and a plant director at a factory respond. However, most of the responses were filled out by a senior manager in the safety department.

Analysis Procedure

For this chapter, several preliminary results of analyses were demonstrated in order to make out an outline. A detailed analysis will be presented later. The analyses conducted were partial ones meant to identify the interrelationships of safety performance with safety activities (from the bottom up) and administrative safety policy and systems, for these aspects are relatively easily shaped by organizational commitments. We employed multiple regression analysis in order to extract significant contributions to the degree of safety performance achieved, which was measured through the labor injury rate (the number of employee injuries per year that resulted in more than four days absence from work) in the construction and petrochemical companies. The interrelationships between safety performance and organizational climate and culture were examined by using a kind of multivariate analysis, namely, correspondence analysis (Qualification Method III: equivalent to the principal components analysis).

RESULTS

Safety Performance Versus Safety Consciousness

The safety consciousness of fieldworkers was evaluated by safety personnel in the company because it was so difficult to get answers directly from fieldworkers. Moreover, it would have been troublesome to obtain workers' behavioral data through questionnaires. Observations made in the field are necessary in order to obtain data on fieldworkers' behavioral styles and forms. Hence, as shown in Figure 11.2, the safety consciousness cluster has the position closest to safety behavior in the safety hierarchical structure. In the near future, we will try to commit to collecting data directly from fieldworkers on their safety consciousness. These results, however, involved indirect evaluation of workers' safety consciousness.

Petrochemical Industry: Headquarters

The multiple regression analysis showed no significant regression overall between safety performance and safety consciousness. The only significant regression identified was between safety performance and the questionnaire item "workers would understand hazards if they took an emergency action under job pressure"($p<0.10$).

Table 11.1 Clusters and Items in the Questionnaire Distributed to the Construction and Petrochemical Industries

Cluster		Number of items	Detailed items (examples)
Safety performance		2	facility failure rate, labor injury rate
Safety consciousness of fieldworkers evaluated by safety section or personnel		14	independence (responsibility) of field engineers, good understanding of hazards, good understanding of local hazards resulting in labor injury or facility failures, good communication with field manager and safety personnel, atmosphere of maintaining safety, motivation to implement safety activities (from bottom up), compliance with safety rules
Controllable safety management	Administrative safety policy and system	6	safety rules, safety award, kaizen proposal, proactive safety audit
	Safety activity	14	hazard prediction, workplace "tidy-up" and "well disciplined," touch-and-call, toolbox meeting, on-the-job training for safety, safety inspection before work, safety posters, collection of near-miss event data
	Acquisition of ISO license	2	ISO 9001, ISO 14001
	Safety management	32	safety training and education, meetings on potential hazards in the workplace, system to report safety problems, position of safety personnel, job standards, systematic incident reporting, prevailing Total Quality Control, company-wide accident notification
	Activities of safety and hygiene section	27	commitments to top management, safety section's amount of work, power of safety section, treatment of safety personnel (part time or full time, staff or line), communication between safety section and management/workplace
Organizational climate and culture		37	daily human relationships, atmosphere that maintains safety in face of productivity, style of decision-making, workers' cooperation, technical qualifications and level, organizational structure, chain of command, traditional or progressive, achievement evaluation, promotion scheme, remuneration scheme, centralization or decentralization

Petrochemical Industry: Factory

The multiple regression analysis showed a significant regression overall between safety performance and safety consciousness ($p<0.01$). The following items were identified as having significant regressions with safety performance: “workers can point out and inform about unsafe acts and deficits in safety” ($p<0.01$), “each worker endeavors to improve facilities and surrounding environment from the safety aspect” ($p<0.05$), “workers understand the organizational strategy and job’s functions and agree with them” ($p<0.10$).

Construction: Headquarters

There was no significant regression overall, however, weak regressions were identified between safety performance and the questionnaire items “workers would understand hazards if they took an emergency action when the amount of remaining tasks was excessive” ($p<0.10$) and “workers have enough knowledge of their company’s policy and management” ($p<0.10$).

Safety Performance Versus Controllable Safety Management or Activities

Petrochemical Industry: Headquarters

There was no significant regression between safety performance and administrative safety policy or systems, either overall or for any single questionnaire item. There was, however, a significant regression overall between safety performance and safety activities ($p<0.05$), and a significant regression was identified between safety performance and the questionnaire item on “near-miss collection system” ($p<0.05$). There was a significant regression overall between safety performance and safety management ($p<0.05$), and significant regressions were identified between safety performance and the questionnaire items “safety manager periodically considers how to improve safety activities” ($p<0.05$), “safety manager queries personnel concerned in an accident analysis” ($p<0.10$), “safety managers encourage workers to attend safety meetings and conferences” ($p<0.05$), and “managers stipulate a unique safety standards” ($p<0.05$). There was no significant regression between safety performance and safety section activities, either overall or for any single questionnaire item.

Petrochemical Industry: Factory

The multiple regression analysis showed a significant regression overall between safety performance and administrative safety policy or systems (p<0.

01). “Proactive safety assessment” ($p<0.01$) and “job kaizen proposal” ($p<0.05$) were identified as having significant regressions with safety performance. There was also an overall significant regression between safety performance and safety activities, and significant regressions were identified between safety performance and the questionnaire items “touch-and-call: if you intend to operate the switch, you point to or touch the switch and call its name for confirmation” ($p<0.05$) and “small group safety activities” ($p<0.10$). There was no overall significant regression between safety performance and safety management, but a significant regression was identified between safety performance and the questionnaire item “safety manager periodically considers how to improve safety training and education” ($p<0.10$). There was a significant regression overall between safety performance and safety section activities ($p<0.05$), and significant regressions were also identified for the questionnaire items “safety section employees are confident about safety issues related to their daily tasks” ($p<0.10$) and “safety section administers unique safety activities that are different from those found in other companies” ($p<0.01$).

Construction: Headquarters

There was no significant regression overall between safety performance and administrative safety policy or systems, safety activities, safety management, or safety section activities. Furthermore, no single questionnaire item showed significant regression with safety performance.

Table 11.2 summarizes the findings presented in this section on questionnaire items showing significant regression with safety performance. The column “safety consciousness” refers to the category of questionnaire items (and so on, for each column thereafter). The list provided in the note to the table indicates items that, through the use of multivariate analysis, were identified as having significant correlation with frequency of labor accidents at the level of 1%, 5%, or 10%.

STRUCTURE OF ORGANIZATIONAL CLIMATE AND CULTURE AND THEIR RELATION WITH SAFETY PERFORMANCE

For items relating to organizational climate and culture, the internal structure of items and their relation with safety performance were analyzed through the use of Qualification Method III, equivalent to the principal components analysis for quantitative values. This type of analysis is known as “correspondence analysis.” This method can reveal the distance between variances on the synthesized variances plane, that is, closer relating variances each other should be plotted in the neighbor on the plane. The level of safety performance was categorized into five ranks and analyzed together with

Table 11.2 Summary of Questionnaire Items Showing Significant Regressions with Safety Performance

Industry	Significance level	Safety Consciousness	Administrative policy / systems	Safety activities	Safety management	Activities of safety section
Construction headquarters	<0.01	□	□	□	□	□
	<0.05	□	□	□	□	□
	<0.10	Nos. 1, 2	□	□	□	□
Petrochemical headquarters	<0.01	□	□	□	□	□
	<0.05	□	□	No. 8	No. 11	□
	<0.10	No. 1	□	□	No. 12	□
Petrochemical factories	<0.01	No. 3	No. 6	□	□	No. 14
	<0.05	No. 4	No. 7	No. 9	□	□
	<0.10	No. 5	□	No. 10	No. 13	No. 15

Note. No. 1: "Workers would understand hazards if they took an emergency action when the amount of remaining tasks was excessive."
No. 2: "Workers have enough knowledge of their company's policy and management."
No. 3: "Workers can point out and inform about unsafe acts and deficits in safety."
No. 4: "Each worker endeavors to contrive facilities."
No. 5: "Workers understand the organizational strategy and job's functions and agree with them."
No. 6: "Proactive safety assessment."
No. 7: "Job kaizen proposal."
No. 8: "Near-miss collection system."
No. 9: "Touch-and-call: if you intend to operate the switch, you point to or touch the switch and call its name for confirmation."
No. 10: "Small group safety activities."
No. 11 : "Safety managers improve and alternate their safety activities periodically."
No. 12: "Safety manager queries personnel concerned in an accident analysis."
No. 13: "Safety manager periodically considers how to improve safety training and education."
No. 14: "Safety section administers unique safety activities that are different from those found in other companies."
No. 15: "Safety section employees are confident about safety issues related to their daily tasks."

questionnaire items on organizational climate and culture, as variances of the correspondence analysis.

Construction: Headquarters

The above analysis was applied to the data obtained from the construction industry (at headquarters). Figure 12.3 shows the results, presenting all variances (questionnaire items) including safety performance. This figure presents the items that are closely associated with a high level of labor accidents (safety performance). These items, shown in Figure 20.3, are Item

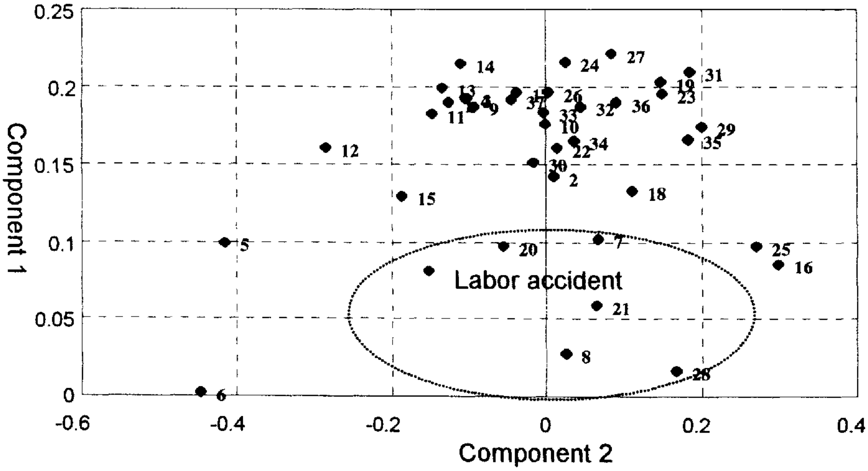

Figure 11.3 Interrelationship of organizational climate and culture items for the construction industry, through Qualification Methods III analysis

20, “inherent atmosphere of manager blaming accidents and mistakes on workers”; Item 7, “a society that focuses too much on status”; Item 21, “importance of traditional aspects”; Item 8, “sometimes not in compliance with rules and standards when under time pressure”; and Item 28, “no consideration for efforts without achievements.”

Petrochemical Industry: Headquarters

Figure 11.4 shows the results of analysis for the petrochemical industry (at headquarters). The following close relationships with safety performance were found: Item 8, “sometimes not in compliance with rules and standards when under time pressure”; Item 6, “depends a good deal on tacit agreements and understandings”; Item 16, “favor compliance with superior’s decision”; Item 28, “no consideration for efforts without achievements”; and Item 35, “importance placed on the deadline and schedule for sharp end.” There were some duplicate items with the construction industry.

Petrochemical Industry: Factory

Figure 11.5 shows the results of analysis for the petrochemical factories. Nearly the same items appeared as those found for headquarters in the petrochemical industry. Several common items were also identified for petrochemical headquarters and factories in the domain opposite the point showing “labor accidents.” These common items include Item 9, “top management’s commitments and concerns about safety issues”; Item 14, “tendency to bring facilities to a halt if there are any doubts”; Item 19,

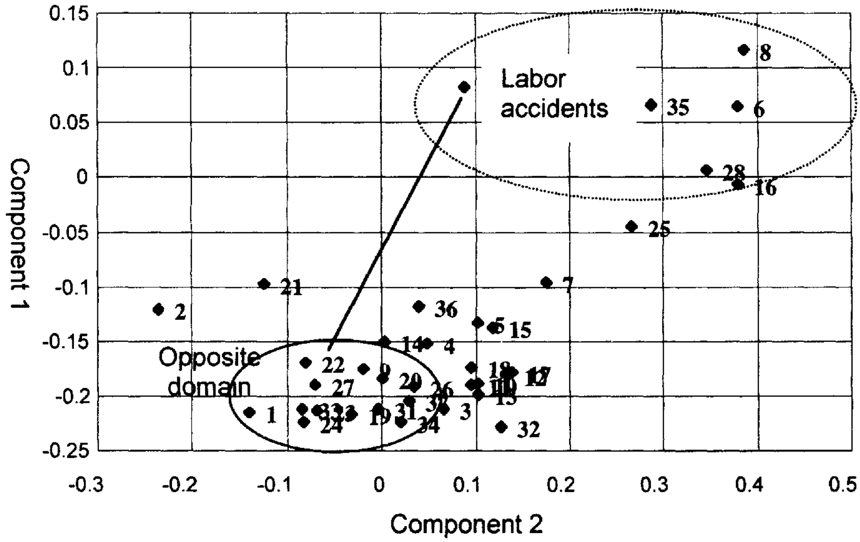

Figure 11.4 Interrelationship of organizational climate and culture items for the petrochemical industry, headquarters, through Qualification Method III analysis.

“workers do not hesitate to consult with safety engineers or with management”; Item 22, “atmosphere that encourages new technology and procedures”; and Item 31, “workers’ compliance with rules and standards.” In the figure, the opposite domain is an area located diagonally across from the point of labor accidents. These factors are considered to be common features within a safety organization that work against labor hazards.

DISCUSSION AND CONCLUSION

The results obtained through the above analysis suggest that there were some differences in the organizational climate and culture between safe and unsafe organizations with respect to the labor injury rate. As Reason (1997) pointed out, conservative and bureaucratic circumstances were found to be conspicuous characteristics of dangerous companies. The typical features of such organizations were described in the section “Structure of Organizational Climate and Culture and Their Relation with Safety Performance.” These features include “production pressures encourage workers to commit violations against safety rules and standards” and “importance placed on achievements without consideration of processes,” which were common to both industries, as well as “depends a good deal on tacit agreements and understandings” and “favor compliance with superior’s decision,” which were common in petrochemical headquarters and factories. In addition, one of these features reveals that daily production pressures have often taken precedence over safety requirements.

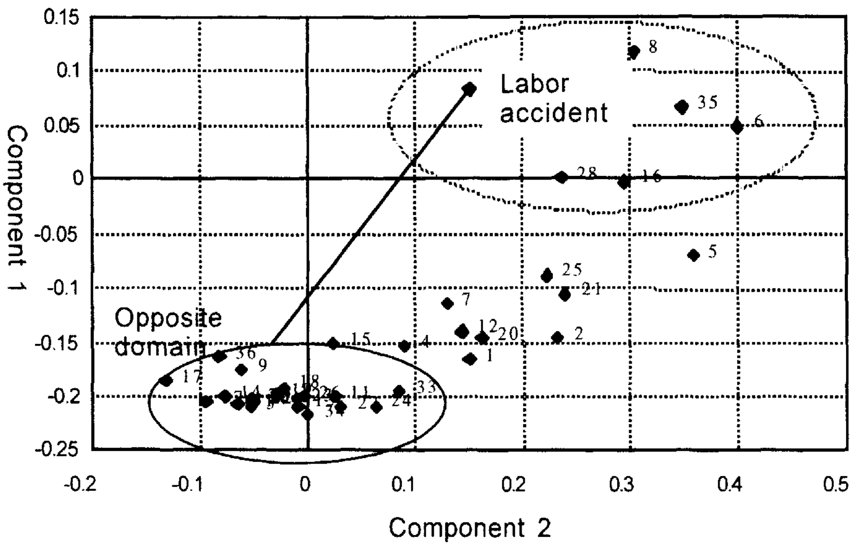

Figure 11.5 Interrelationship of organizational climate and culture items for the petrochemical industry, factories, through Qualification Method III analysis

The features located opposite the unsafe organization are thought to be found in progressive and democratic organizations with the following characteristics: "assigning the competence to make a decision for a safety predominance," "an atmosphere urging the challenging spirit," "not hesitating to consult with safety engineers and with management," "compliance with safety rules and standards," and, most crucial, "making top commitments to safety." These features indicate an organizational climate and culture with a strong capacity to fight against risks and hazards. Reason (1997) suggested that "3C" ("cognizance, competence, and commitment") are fuel for the safety engine—a motor that promotes safety. Our results also point to the importance of competence and commitment; they suggest as well that a challenging spirit and the ability to adapt to change may be necessary characteristics for the safe organization. The crucial factors that Diaz and Cabrera (1997) identified are also confirmed by our results; some examples include whether workers comply with the safety rules and standards, the emphasis on productivity versus safety, and management commitment to safety. Zohar (1980) identified management commitment as the most critical factor, whereas Haber et al. (1992) listed the following: communication, decision-making and problem-solving, standardization of work, and management attention. Our study also recognizes communication and decision-making as important features of companies with excellent safety records. Companies that have smooth communication between safety managers and fieldworkers, and between management and fieldworkers (as suggested in this study), are considered to have a good communication climate. Decision-making is one factor determining to what extent there is a flexible organizational culture (Reason, 1997). The decentralization of safety issues seems to be an important part of the flexible organizational culture, whereas an atmosphere that maintains compliance with rules is a key aspect for the organizational climate. This study identified a progressive atmosphere as another factor that can stimulate safety behavior, and even safety performance.

However, because it is difficult to directly commit to safety issues (see the first section of this chapter), we believe that commitments should be made through safety management. The methods of safety management include administrative safety policy, safety activities, administrative safety management, and safety section activities. To evaluate the effectiveness of how to implement such management, multiple regression analysis was carried out in order to clarify these methods. The results obtained were somewhat contrary to our expectations. The analyzed data of the headquarters (construction and petrochemical industries) provided only a little information on significant regressions. On the contrary, the data obtained from petrochemical factories offered relatively rich information (see Table 12.1). This situation is to be expected because fieldworkers constantly confront dangerous situations and experience safety problems immediately. Furthermore, the chemical industry is characterized by relatively large companies; traditionally, the commitment of large companies to safety management is systematic, particularly in factories.

Significant regressions identified for the categories related to observed safety consciousness were "daily checking of other workers' unsafe behavior and consideration given to facility improvements" and "understanding the hazard and organizational policy, the organizational strategy, and the job functions." The latter point relates to a flexible organizational culture, because effective organizational decentralization can only be established when the subcomponents of an organization have the same goal and strategy as senior managers have (Reason, 1997). As for safety management and activities, the following were found to be effective: "proactive safety assessment," "job kaizen proposal," "touch-and-call," "small group safety activities," "implementation of unique safety activities and standards," "a near-miss reporting system," and "change in safety training and education."

Herzberg (1959) proposed the motivation and hygiene theory, which states that there are two kinds of organizational factors: hygiene factors related to contexts and environments in the workplace, such as supervision, the work environment, salaries, human relations, and status, and factors that motivate people, such as achievement, recognition, the work itself, responsibility, advancement, and growth. Reason found that hygiene factors do not affect people's motivation levels and that a high level of hygiene and a low level of motivation make for an "unrocked boat," that is, a routine and dull environment. Both factors are necessary to make a healthy organization. Effective safety management can be classified with motivation factors, because most of its strategies relate to fieldworkers' commitments to protect themselves from hazards and dangers. Actually, in some factories, top managers have been implementing policies that give awards and status to employees with excellent safety records. It is believed that safety motivation can play an essential role in promoting safety. Diaz and Cabrera (1997) also recognized the positive contributions to be gained from unique safety activities. Passive safety management, such as safety rules and policy, safety posters, and specific safety periods, those prepared in every organization can be categorized with hygiene factors. However, these factors are not primary, because they do not become motivators. Finally, the reporting of near-miss events relates to the reporting culture (Reason, 1997), which is a controllable subcomponent of safety culture.

This study describes the interrelationship between safety performance and organizational factors, though at present it is limited to measuring safety performance through the labor injury rate. Facility failures—failures involving machinery—will be discussed in the near future; we will first need to define the facility failure itself, which is problematic because the definitions used in several industries are so different from each other. In the end, as Zohar (1980) and Diaz and Cabrera (1997) concluded, it may be difficult to find an interrelationship between facility failures and organizational factors. In addition to data on safety performance, we will collect various data on organizational factors and their internal structures.

Acknowledgement

The authors express special thanks to Dr. Hanayasu, Mr. Suzuki, and Mr. Shoji at the National Institute for Industrial Safety (NIIS), the members of NIIS for their joint study to prepare the questionnaires and distribute them to the construction industry. We are also grateful to Professor Morita, who made recommendations to selected companies in the petrochemical industry. Finally, we would like to thank the federation of the construction industry, the safety division, and the respondents from the participating companies in the construction and petrochemical industries.

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CHAPTER TWELVE
Developing a Safety Conscious Work Environment at Millstone Nuclear Power Station

JOHN S.CARROLL AND SACHI HATAKENAKA

In early March of 1996, TIME presented a cover story about harassment and intimidation of employees who brought safety concerns to management at Millstone Nuclear Power Station. The US Nuclear Regulatory Commission then issued an unprecedented Order that directed the operator of Millstone to devise and implement a plan for handling safety concerns raised by employees and ensuring a safety conscious work environment free from retaliation and discrimination. During the next three years, there were major changes in management personnel, training, communication patterns, program structures, and human relationships. There were also personal transformations. Most of these changes were not planned at the start, but emerged from a wide range of leaders and contributors inside and outside Millstone Station. Millstone Station is operating again, the work environment is healthy but fragile, and there are many challenges ahead as deregulation and downsizing play out in this industry. The story of Millstone's development of a safety conscious work environment has many lessons for the nuclear power industry and other industries.

In early March of 1996, Time presented a cover story (Pooley, 1996) about harassment and intimidation of employees who brought safety concerns to management at Millstone Nuclear Power Station. The US Nuclear Regulatory Commission (NRC) was receiving approximately 50 allegations per year from Millstone, among the highest at any nuclear power station (NRC, 1996), All three units at Millstone were at that time on the NRC "Watch List" of plants deemed to need more regulatory attention, due to a combination of operational deficiencies, weaknesses in documentation of the design basis/licensing basis, lack of demonstrated improvements, and employee allegations.[1] Each of the three units had been shut down by utility management to deal with particular problems. In June, the NRC placed all three units into Category 3 of the Watch List, which meant that the units could not be restarted without an affirmative vote of the NRC Commissioners establishing that substantial progress had been made to correct the issues.

Although other plants have been placed on the Watch List, the NRC Order (Miraglia, 1996) included an unprecedented requirement. Millstone Station had to demonstrate a safety conscious work environment in which employees would feel comfortable raising safety concerns to management without fear of retaliation and management would take appropriate action on these concerns. There had been no physical event threatening the integrity of the reactor core, no release of radioactivity, no sudden loss of safety functions. The Millstone "event" was a loss of regulatory "margin" (i.e., the NRC no longer accepted less than strict compliance or promises of improvement) in a context of political and media pressure.

At the time it occurred, Millstone appeared to represent one of the most important events in the US nuclear power industry since Three Mile Island—a human systems and regulatory crisis. The NRC has subsequently decided not to make Millstone a prototype, and at least some Commissioners believe Millstone was a regulatory "overreaction" (Diaz, 1998). However, the Millstone episode continues a transformation of the nuclear power industry from a focus on engineered safety features to an appreciation of the management of a high-hazard work system.[2] The regulatory sensitivity to the work environment challenged Millstone Station to establish programs and institutions to define, develop, and maintain a safety conscious work environment, and its response has been closely watched by the nuclear power industry and others.[3]

In this paper, we will describe the events and the strategies that were developed from 1996 to 1999 to create and sustain a safety conscious work environment at Millstone Station. During this time the first author was a member of the Nuclear Committee Advisory Team, which was created in 1996 to advise the Nuclear Committee of the Board of Trustees of Northeast Utilities (NU) regarding nuclear power operations at Millstone, Seabrook, and Connecticut Yankee nuclear stations. In this capacity, we met regularly with staff responsible for employee concerns and safety conscious work environment, observed meetings, and read documents. As additional preparation for the writing of this paper, we conducted 18 interviews with key people from NU System companies, Millstone Station, the NRC, and the Nuclear Energy Institute, an industry lobbying group, who had responsibility for developing or overseeing these new activities, or otherwise brought an important perspective to the events.

THE STORY

Millstone Station is located in Connecticut on the shores of Long Island Sound. The Station includes three nuclear power units of different designs:

Unit 1 is a General Electric reactor commissioned in 1970, Unit 2 is a Combustion Engineering reactor commissioned in 1975, and Unit 3 is a Westinghouse reactor commissioned in 1986. Subsidiaries of NU together own all of Units 1 and 2, and a majority of Unit 3. Northeast Nuclear Energy Company (NNECO), a wholly owned subsidiary of NU, operates all 3 units. In total, the 1996 workforce had over 2000 NNECO employees and over 1000 consultants and contractors.

Fall From Grace

During the 1970s and 1980s, Northeast Utilities was widely recognized as a leader in the nuclear power industry. It was especially respected for its engineering organization, and was a pioneer in the development and use of Probabilistic Risk Assessment, a technique for analyzing and managing the risks of damage to the uranium fuel in the reactor. However, the utility expended tremendous resources building Unit 3 in the 1980s, at a time when many utilities were encountering increased public resistance to new plants and several either stopped projects short of completion or faced severe financial hardship. This also corresponded with a change of leadership as Leland Sillin, revered at Northeast Utilities as one of the pioneers of the industry, retired as Chief Executive Officer (CEO). Also, an external consultant's report in early 1987 emphasized impending deregulation and the need to compete with other sources of energy, and recommended cost reductions throughout the NU system. The result at Millstone was a focus on running the plants without spending unnecessary funds (for example, travel budgets and memberships in industry organizations were reduced), appreciation of managers who could get things done within the budget, and less attention to the engineering organization now that the plants were operating.

By the early 1990s there were signs that Millstone was not keeping up with an industry where standards of performance were increasing each year. Engineers and other employees were complaining, sometimes publicly, that management would not listen to their concerns about design and operational issues. Backlogs in maintenance work, engineering work, modifications, and corrective action were growing and management seemed unwilling to recognize their seriousness. Funds for improvement programs sometimes seemed to be withdrawn or folded into new programs before the problems were solved. When management appeared unresponsive, unhappy employees looked for other issues, sometimes raising dozens of issues, and there was a cancerous spread of dissatisfaction.

The Institute of Nuclear Power Operators (INPO) and the NRC began to comment on Millstone's inability to resolve known problems and the deterioration of the safety culture, yet each INPO and NRC report included praise along with criticism. INPO reports suggested that the decline in the early 1990s had been reversed by the end of 1994, particularly at Units 1 and 3. In August 1993, non-conservative on-line valve maintenance led to speculation that the NRC would put Millstone on the watch list in January 1994. When they did not, it again provided a mixed message—how much autonomy did Millstone have? "*The NRC gave us a lot of rope… They didn't want to do it* [put the plant on the Watch List]. *They were meandering through unfamiliar turf.*"[4] At the end of 1994, the NRC reorganized their additional evaluation efforts to focus on Unit 2, and Millstone management decided to extend the Unit 2 refueling outage to identify the causes of deficiencies and upgrade the corrective action process. In March 1995, NRC senior managers met with the Northeast Utilities Board of Trustees to communicate NRC's concerns, especially regarding Unit 2. The NRC pointed to limited success in resolving numerous operational, quality, and teamwork issues, and inappropriate responses to employee safety concerns. At the June 1995 NRC Senior Management meeting, Units 1 and 3 were not "discussion plants," a step that usually precedes increased enforcement and possible Watch List status. In the same month, the NRC agreed that Millstone Unit 2 had demonstrated sufficient progress to support restart but cautioned that longer-term corrective actions were still in progress.

During the next year, the NRC continued their involvement with additional inspectors and oversight. In December 1995, the NRC established a review group to evaluate the handling of employee concerns and allegations by both NNECO and the NRC itself. Millstone Station was placed on the Watch List in January 1996, and additional inspections and investigations were initiated to examine the Unit 1 fuel off-loading practices and other concerns about implementation of license requirements. When Unit 1 shut down for refuelling in November 1995, and the other two units shut down in February and March for unrelated equipment problems, NRC issued letters requiring all three units to demonstrate their compliance with their licenses, regulations, and safety analyses, before they would be allowed to restart. These letters focused on technical issues of operations and demonstration of an appropriate design and licensing basis (i.e., that equipment specifications, actual on-site equipment, and operating rules are fully documented, up to date, and consistent).

In October 1996, the report of the NRC review group on Millstone employee concerns was issued. The report concluded that an unhealthy work environment, which did not tolerate dissenting views and did not welcome or promote a questioning attitude, had existed at Millstone for at least several years:

This poor environment has resulted in repeated instances of discrimination and ineffective handling of employee concerns… The vast majority of employee concerns and allegations that were submitted at Millstone represented little safety significance; however, many involved potentially important procedural, tagging or quality assurance problems, and a few were ultimately determined to have safety significance… None of the findings of this team are new. Every problem identified during this review had been previously identified to NU management…yet the same problems were allowed to continue (Hannon, Mohrwinkel, Thadani, Huey, Pelton & Nagel 1996, p. i–ii).

The review was also critical of NRC's own process for handling allegations at Millstone. It cited issues such as inadequate sensitivity and responsiveness, inadequate follow-up and enforcement, ineffective inspection techniques and performance measures, cumbersome interactions between NRC and Department of Labor over employee issues, and ineffective implementation of an allegation program.

NRC then issued an Order that directed NNECO to devise and implement a plan for handling safety concerns raised by employees and ensuring an environment free from retaliation and discrimination. The plan had to address the causes that had brought about the degraded work environment. The Order also required NNECO to nominate for NRC approval, and then contract with, an independent third party to oversee the plan and its implementation. The third party would develop an oversight plan for approval by the NRC that would detail the requirements of the Order and how progress would be monitored through audits, employee surveys, and so forth. Oversight by the third party would continue until NNECO demonstrated, by performance, that the conditions leading to the NRC Order had been corrected.

In essence, NRC added to its technical requirements for the restart of Millstone units a dramatic articulation of new expectations for a nuclear power plant, with verification required by an independent third party as well as by the NRC. The unique action was undoubtedly prompted in part by the Time article, public embarrassment that NRC had not acted earlier, and a new Chairman of the Nuclear Regulatory Commission seeking to take an aggressive stance. By issuing the order requiring a demonstrated safety culture, NRC *"tried to shake up management of [the] plant."*

Stating the requirement that Millstone demonstrate a safety conscious work environment does not specify what these words actually mean. There were no regulations defining safety culture. What can you do to change a culture and how "safety conscious" does the work environment have to be? How do you know that safety concerns are being handled appropriately, and how do you prove this to consultants, regulators, and vigilant publics? The NRC itself was poorly prepared to deal with safety culture. As mostly engineers, their skill set was primarily technical and their experience base was limited. The third-party oversight organization *"gave the NRC a huge benefit at almost no cost,"* bringing its own expertise and assuring the NRC that independent auditors were on site with the tools to monitor the work environment.

The Initial Millstone Response

Attempting to diagnose the underlying problems with Millstone's work environment, several reports and analyses identified attitudes, values, and behaviors promoted by senior management. At the end of 1995, Bob Busch, Chief Operating Officer of NNECO, had requested a self-assessment of the organization, and the resultant Millstone Employee Concerns Assessment Team Report (Quinn et al, January 1996) had captured the same issues raised earlier by the NRC and later in other reports. A lot of discussion followed, but little sustained action. NRC's observation of this lack of effective response, in part, may have led to the Order. The NRC report on employee concerns (Hannon et al., 1996) reiterated what had been found by the earlier Millstone report as well as by the Fundamental Cause Assessment Team Report (Bonaca, July 1996) commissioned by the Nuclear Committee of the NU Board of Trustees. These reports agreed that management was insensitive and arrogant, overbearing and intimidating, lacking interpersonal skills, and focused on cost-cutting. It seemed clear that current senior management, regardless of their potential to change, had lost credibility with employees and external audiences. New management would have a better chance to help Millstone move forward and avoid bankruptcy. The utility was spending one million dollars per day per plant to make improvements and buy replacement power for customers; the share price had plummeted from $26 to under $8.

Responsibility for recovery of Millstone was placed in the hands of Bruce Kenyon, hired in September 1996, to replace Bob Busch as second in command to CEO Bernie Fox, who would retire in 1997 and be replaced by Michael Morris. Kenyon had responsibility for the NU nuclear program including Millstone, Connecticut Yankee (also shut down and later decommissioned), and Seabrook Stations. Kenyon insisted on full authority to do what was needed, and the Board of Trustees granted that authority including the new title of CEO for Nuclear Power.

Kenyon knew coming into Millstone that employee-management relations were *"severely damaged"* and that a foundation of trust was needed on which to base an effective employee concerns program, to build a safety conscious work environment, and to conduct the work needed to restart the Millstone units. He would need to lead the effort to reestablish that relationship. He calls it *"the toughest challenge I faced."* He had worked at Millstone 20 years before and therefore knew many of the leadership team and had a perspective on the station. His strategy was to bring a clear set of values, communicate openly, and move decisively to change the existing management style. Throughout the next months, Kenyon would meet regularly with small work groups and in large all-hands meetings to give information and encourage two-way communication: *"It shocked them to get candid answers."* Upon hearing Kenyon at his first Commission meeting say that he found NU *"essentially dysfunctional,"* an interviewee from the NRC remembers thinking, *"here's a fellow who at least recognizes the problem."*

At 8am on his first day he called all employees onto the lawn and introduced himself and his values: high standards, openness and honesty, commitment to do what was right, and two-way communications. He told them he would take two weeks to assess the situation and then announce his plan. He then met briefly with all Vice Presidents and Directors (Directors are the level below Vice Presidents, then managers, and supervisors are first-line management) and shocked them by giving them an assignment to grade each of their peers, comment on strengths and weaknesses, and personally return the grade sheets to him in the next week. In the third week, he fired two of the three Vice Presidents, demoted the third, and announced a plan for recovery teams from three other nuclear utilities with experience recovering troubled plants[5] to provide leadership for the three Millstone units and help Millstone build its own leadership capabilities. This was intended as a dramatic break from the past, a signal that the new leadership was determined to bring change.

Kenyon was not prepared, however, to deal with the safety conscious work environment issue and the sensitivity of Millstone employees. He had *"never encountered a culture as broken."* He had worked at a plant that was like a family, high in trust. In his previous experience, employee issues had been dealt with by management and the organizations had never needed a special Employee Concerns Program to receive and investigate employee concerns in a confidential manner, or the layers of oversight required by the NRC Order. At Millstone, management actions were regarded with suspicion and distrust. For example, when Kenyon relieved the three Vice Presidents, one was Senior VP of Oversight, and there was an immediate perception by some that this was another attack on independent oversight. Kenyon asked INPO to recommend a Navy Admiral who could run Oversight. They suggested two, and Kenyon hired Dave Goebel in October 1996.

Millstone had an existing Employee Concerns Program (ECP) that was inside Oversight. When Goebel first arrived, he was asked to write a plan for a new Employee Concerns Program to replace the current, ineffective one. ECP had a reputation among employees as a tool of management to *"make them look good and feel good"* and some managers considered it *"a legal defense fund for bad employees."* The current Director of ECP already had been informed he would be leaving. Goebel brought in Ed Morgan to be Director of ECP; Morgan had been his chief of staff in the Navy, and was then working at Rocky Flats. He had no experience with commercial nuclear power or NRC regulation, and no opportunity to hear from the departing Director.

From his experience, Goebel believed an effective ECP had to be based on employee involvement, and he therefore asked for volunteers to help write the program. Expecting to select 12–16 from a large pool of volunteers, he received only 20 applications and took them all. Believing that someone from the team that produced the 1996 Millstone Employee Concerns Assessment Team Report should be on the EC task force, Mike Quinn and another member volunteered, and Quinn was *"drafted"* to lead the task force. It became apparent after two meetings that almost everyone in this task force had an axe to grind and that there were a lot of conflicts within the task force. Two facilitators were brought in to help the group. Kenyon and Goebel stuck with it, meeting with the task force two or three times a week for an hour or more, trying to build mutual respect and create a workable plan. The task force produced a program that made untenable demands on NU, and the task force refused to make changes. Over a weekend, a shorter report was drafted for formal NU submission to the NRC, and all parties agreed with the approach.

As Director of ECP, Morgan moved rapidly to structure and staff the ECP process. He categorized concerns into separate bundles that could be handled appropriately, lowered the threshold of issues that were reported to ECP, and set high standards for work quality. An early mistake was marketing ECP to the workforce too soon, leading to a deluge of concerns and no time to investigate them. Hiring new contractors for this workload took time and there were problems with some investigators. It was mid 1997 before there were enough resources to handle the work load. Above all, Morgan brought *"the sensitivity to see both sides of an issue."* For example, the low threshold encouraged a lot of issues from contractors who may not have understood the plant. A supervisor could easily lose patience and say something inappropriate, such as, *"this is a no brainer."* The contractor is then upset, and the supervisor gets labeled an intimidator. *"Millstone lost key people who left under that kind of pressure."* Morgan was able to see both sides, and how both parties could become victims.

An unusual recommendation of the employee task force was the creation of an Employee Concerns Oversight Panel (ECOP). The task force members wanted to have an independent voice, to report directly to Bruce Kenyon, and to oversee the Employee Concerns program. Yet the Panel itself was filled with disaffected employees who argued continually with each other, but who had to be treated with extreme care by management because they would have to give their own opinion of safety conscious work environment and were therefore critical to restart. Mike Quinn, who had led the Millstone Employee Concerns Assessment Team in 1995, was named Manager of ECOP. Over time, the panel members and management evolved a workable role for ECOP to assess the effectiveness of the action plan through surveys and interviews, act as another communication channel for employees, and participate on and observe key activities to implement management plans. The existence of ECOP *"sent a message to the workforce that employees could act as oversight of management."* ECOP members' own attitudes and behaviors were changed by their participation, especially the full-time ECOP representatives. Some of the ECOP members became strong facilitators for later training sessions.

Also in January, NNECO nominated Little Harbor Consultants to be the independent third party oversight team. Dave Goebel and Bruce Kenyon urged that the team be broadened by the addition of Billie Garde, a lawyer with extensive experience defending whistleblowers and advocating for employees, who also had been one of the facilitators for the employee concerns task force. Little Harbor was formally approved as third party oversight in June. Even before its approval, Little Harbor had developed a list of 12 components of an ideal safety conscious work environment, so that it could propose how it would evaluate the NNECO plan (Little Harbor Consultants, 1998). These components included: (1) senior management policy that places priority on safety over production, supports worker rights to raise safety issues and ensures freedom from harassment, discrimination, and intimidation if they do so, (2) training for all managers regarding treatment of employees who raise safety concerns, (3) favorable employee perception of the policy and its implementation, no evidence of a "chilling effect" (unwillingness to report safety issues for fear of retaliation), and worker recognition that line management will address safety issues with an effective correction action program, (4) an Employee Concerns Program to handle concerns that do not go to the line organization, and (5) periodic independent and self-assessments to monitor and improve performance. Little Harbor concluded that NU's plan was too narrowly focused on the Employee Concerns Program, and the plan was then revised to include several company initiatives that had not been mentioned in the initial version of the plan.

By April 1997, a Safety Conscious Work Environment (SCWE) initiative was established. This was intended to broaden the change process, recognizing that the ECP was only part of the solution. *"Ed Morgan could build an effective ECP, but only the line organization could develop a healthy work environment."* As Paul Blanch put it, ECP could *"put out a fire, but it wasn't fire protection."* Blanch, an engineer at Millstone for many years, had been harassed when he brought technical concerns to management in 1989 and 1992, had taken the company to court and left in 1993, and then was rehired by Bruce Kenyon as a consultant to help Millstone develop SCWE.

At a meeting with all the Officers, Kenyon made the surprising announcement that the SCWE initiative would be the responsibility of Vice President for Operations Mike Brothers. Brothers is a quick thinker, extremely knowledgeable about the technical features of Millstone, and a rapid-fire talker who doesn't suffer fools lightly. He admits that he was viewed by the workforce as a *"taskmaster."* Many employees thought putting him in charge of SCWE introduced a *"fox in the henhouse."* Brothers, and most of Operations, had come from the nuclear Navy, a culture of *"locker room teasing...people are verbally brutal to each other and* *develop a tough shell,"* and they immediately close ranks to outside criticism. *"A lot of people were scared of me, although I knew I wouldn't do anything wrong. I didn't realize the power of perceptions… I don't hide my emotions… Now I try to pick my audiences more carefully. I became one of the best apologizers."*

Brothers had little idea what he was expected to do. Yet, his emergence as the SCWE leader gave the effort a lot of internal authority and at the same time forced him to learn new skills in a hurry. Brothers appointed Mike Gentry to be Manager of a SCWE group with five people under him, and this group was asked to find problem areas and formalize action plans to deal with them. The SCWE group began to help the line managers learn about SCWE, how to work with employees and communicate better. Although they were making some progress and the senior leadership was saying the right things, management *"didn't know what SCWE was"* and what they themselves would have to do. Management *"thought it would be intuitively obvious."* Leadership training started in offsite meetings in May with help from Billie Garde and Little Harbor. The feedback from the training sessions was that more training was needed—it *"whet our appetite."*

The Watershed Events

Two events in the summer of 1997 challenged the commitments and resources of individuals and the organization and became defining experiences for management and workers. The first event was initiated by management's discipline of 20 members of the Training and Operations Departments on grounds associated with the accuracy of training documentation from two years before. The former Training Director, then serving as a Nuclear Oversight Director and an outspoken critic of current performance, was among those disciplined. These disciplinary actions triggered an uproar at the site to what was perceived as an unjust and untimely management action, including the perception that the former Training Director was retaliated against (a potential "chilling effect") for his criticism of management. Although an independent investigation determined that the levels of discipline were generally appropriate, it was apparent that management had failed to anticipate the potential impact of the disciplinary action on the organization and to undertake timely communications to minimize the potential for a chilling effect. A major lesson learned was that *"perception is reality."*

The second event was initiated by the termination of two contractors working on the Motor Operated Valves (MOV) project by contractor management on grounds of alleged poor performance. These terminations were approved all the way to the level of Unit Recovery Officer, who reported to Bruce Kenyon. The two contractors had raised issues concerning the adequacy of the work being done on their contract, a form of "protected activity" with legal protections against retaliation. Kenyon initially supported the terminations, believing everyone had honest intent. Ed Morgan, Director of the Employee Concerns Program, made immediate and repeated attempts to get this decision overturned. Kenyon became convinced the decision had been a mistake and reversed himself. Subsequent investigation by ECP revealed that both individuals had adequate performance records and that the terminations were not justifiable. And again, the chilling effects of the terminations were not anticipated. The response to this event created enormous credibility for the ECP in the eyes of the Millstone workforce.

Further, this event was a personal turning point for Mike Brothers, who was in charge of SCWE. Prior to the event, he was *"going through the motions… I didn't believe anyone would harass someone who brought forth safety concerns… After all, I live near here."* But the week following the terminations, he was called down to the Little Harbor offices where Ed Morgan and his investigator presented the case to Little Harbor. Brothers says, *"it was one of those moments your perception changes…clear-cut harassment…a watershed for me."* Brothers acted that day to put the terminated contractors back on retainer while the case was investigated, and a week later both were offered back their jobs. The contractor supervisor was asked to leave.

The event forged a new relationship between Mike Brothers and Little Harbor. Little Harbor and NNECO had struggled through the first six months of their unusual relationship because they did not know how to work together effectively. Little Harbor thought they were an auditor; Millstone management thought they were not allowed to talk directly to them, but only in writing or through a third party. Around the time of the MOV event, Little Harbor began to give insights from their broad experience at other plants and other industries. An interviewee from the NRC said, *"Little Harbor operated in ways we didn't imagine… We expected them to monitor… They became more proactive in assisting with thoughts, suggestions."* Millstone management, such as Mike Brothers, were now much more open to their help, and communication became more open and effective in both directions. Brothers also developed a strong relationship with Billie Garde, whom he calls, *"one of the most brilliant people I ever met…a magnet for people to talk to her."*

From the MOV event and discussions with Little Harbor, Brothers began to learn that *"SCWE makes sense, if done right,"* and the pace of action accelerated. As a result of extensive management discussion, an Executive Review Board (ERB) was created to review all disciplinary action from written reprimand to termination. The ERB consisted of Mike Brothers, Judy Gorski, (Director of Human Resources), a representative from Contracts, and Mike Quinn from ECOP (who later assumed an observer role due to concern over conflict of interest with the ECOP role). This was first applied to all NNECO employees, but then extended to all contractors. Because of co-employment rules that inhibit companies from directly managing contract employees, this was a bold step, possibly unique at the time. As Brothers said, *"I'll take the $50,000 lawsuit on co-employment to avoid the $1 Billion lawsuit on safety."* Eventually, all contractors agreed to the process, many of them came to value it for the protection they got, and some tried to set up the same process with other customer companies. Over time, the ERB became increasingly important to give employees more trust in management, to create a learning environment with multiple perspectives to help both ERB members and managers who presented their cases think through their decisions, and then to help those people use their learning from the ERB experience to manage their own organizations. Management began to ask the ERB for guidance and advice even before they took personnel actions.

The third key event during the summer was a visit by senior management to South Texas Project, a nuclear power plant that had emerged from a hostile work environment and numerous problems to become an industry leader. Millstone management had thought it was impossible to discipline an employee engaged in protected activity, and therefore to have both a safety conscious work environment and an accountable organization, but at South Texas Project they saw a working model that combined both. Key managers including Mike Brothers, Ed Morgan, and Mike Gentry also got to know each other better during the trip. During the next year, many visits to South Texas Project ensued. Beth Nilsson, who had spent several years working in organizational development at South Texas Project and other troubled plants, was invited to speak in September about SCWE at Millstone. Nilsson Associates was later asked to assess Millstone, and in January they were asked to supplement NNECO activities with other team building and organizational development functions.

Institutionalizing SCWE

In November 1997, at a meeting of the Officers, it became obvious that if Unit 3 was not restarted soon, *"it would be all over."* Mike Brothers knew more about Unit 3 and its people than anyone, yet his time was consumed by his collateral duties with SCWE. Dave Amerine, who had arrived in September and taken over Nuclear Engineering and Support, which included Training, volunteered to become VP of Human Resources and be responsible for SCWE. This would allow Brothers to focus on the restart of Unit 3. Amerine had a *"reputation in his prior company"* as a tough taskmaster with several employee concerns written regarding him. *"People said, they put you in charge?"* But he had responded well to some minor events in the Training Department. Amerine was *"an engineer par excellence, the least right-brain person I know, but he was a learner who took charge."* Like Mike Brothers before him, he was changed by the job: *"when you teach, you learn."*

Taking over the daily 8am meetings Brothers had been having with SCWE, Amerine renamed it the "People Team." It had representatives from Human Resources (Judy Gorski), Legal, ECP (Ed Morgan), ECOP (Mike Quinn), SCWE group (Mike Gentry), two of Bruce Kenyon's assistants, and Nilsson Associates. The Nilssons provided team-building sessions, and the People Team meetings became an opportunity to share perspectives and learn from each other. Amerine brought a *"respect for structure"* to a team that had a lot of empathy and caring, and a lot of people skills, but could *"go off in eight directions at once."* Meetings had not been organized efficiently *"like an engineer is."* In their response to problems, *"we were like Keystone Kops at first."*

The People Team made flow diagrams for ECP. They flowcharted diagnoses of the legal aspects of problems and chilling effect, and placed these on laminated cards every manager could carry in their Day Timers. They developed clear processes for dealing with acute and chronic problem areas. For acute emergent problems, such as the MOV event, the team structured a rapid response capacity. Criteria were established, and any group at Millstone could initiate a rapid response by calling in one of four leaders: Mike Gentry, Judy Gorski, Ed Morgan, or Mike Quinn. The rapid response logic treated a people problem analogously to a plant problem: first, stop the situation; second, stabilize the situation; third, develop a plan to address the situation. For slower-developing chronic problems, criteria were developed to label a group as a Focus Area if people in that group had expressed reluctance to raise issues to management or their management was unwilling or unable to address issues once raised. In effect, Millstone was divided into over 400 groups, to the level of every supervisor. At one point in time, there were 33 Focus Areas, each with a plan for addressing their problems and monitoring progress. At the 8am meetings, the People Team would sort out who had the lead in a Focus Area, and then request other help. Typically, the Focus Area interventions involved facilitation and team building, trying to find out the real problems, and working with everyone involved to solve them.

Oversight became the first focus for this activity, since over one-half the problems were there. The old NU, focused on engineering to build new plants and operations to run them, was perceived to have given lesser attention to Oversight. It was believed that some people who were extras or difficult to work with wound up in Oversight. There were a lot of managers supervising only one, two, or three other people. At first, SCWE people interviewed Oversight people in a clumsy way that generated more issues. Over time they learned how to work with the Focus Area groups.

The vast majority of issues coming to ECP and the People Team were human resource issues, not safety issues. Although the ECP was structured in response to the NRC Order that focused on safety concerns, most issues were either personnel matters around salary, benefits, and promotions, or interpersonal matters around supervisory relationships and personality conflicts. In a normal organization, these would be dealt with by line management and the Human Resource (HR) Department. At Millstone, line management lacked people management skills and HR was ineffective and mistrusted. The nuclear power industry is *"not high on people skills, for example, few can read nonverbal signals."* A *"tremendous paradigm shift"* was taking place. Managers who were *"forceful and ran a tight ship wouldn't last in this place."* They had to manage differently, to *"think before they act, and think before they speak."* It was tough for managers to *"admit you need help."* Most figured it out, many after being put on performance improvement plans. But about 40 were replaced, and *"this got everyone's attention."*

Part of the process of developing SCWE and improving relations between managers and workers was learning to understand the language and feelings that people experienced. They had to *"learn the difference between anger, hurt, and a chilling effect."* Workers would talk about being chilled—unwilling to bring concerns to management—and yet their explanations focused on how their confidence in management had been shaken, not on fear of reprisals. The Nilssons played a major role in educating the site in change models that articulate how people go through stages of anger, denial, exploration, and acceptance. *"We had wasted time mitigating a [supposed] chilling effect that was working through anger."*

At NNECO, the Human Resource Department was a central function administered from headquarters, a one-hour drive from Millstone. According to one respondent, for years, *"HR had kowtowed to management,"* in deference to their strong and sometimes arrogant style. If employees raised an issue, HR might try to advocate for them, but management would *"send them back to their corner."* HR was slow and unresponsive to employees, never having more than three or four staff at Millstone to provide service to thousands of employees. Efforts to support change at Millstone by hiring new people, restructuring salaries, changing overtime or other personnel policy, were stymied by HR's slow and conservative responses. At Bruce Kenyon's request, HR sent a VP to the Millstone site to break through the long chains of communication. Unfortunately, he alienated people by trying to tell them what to do. In May 1997, he was replaced by Judy Gorski, who began to build a customer-oriented HR at Millstone. She set standards that HR would call back the same day, and resolve issues within three days. She worked on HR fundamentals such as the dysfunctional performance appraisal system in which managers never said anything negative, documents were not kept, and reviews had no impact. HR also began to develop and offer tools for managers such as facilitated sessions where managers and subordinates could discuss issues and expectations, and assimilations for bringing new supervisors into a work group. In spite of these improvements, HR still had a long way to go in gaining plant confidence.

In January 1998, Cheryl Grise, Senior VP of Administration for all of NU, received a phone call from all three Little Harbor consultants. They said, *"if you don't get down here this Order won't get lifted… We don't see anyone else who can get this done… We need a senior manager who understands HR and Legal… You need to be here Monday morning and full time."* Little Harbor's recommendations were not being carried out fast enough; there was a lack of urgency. HR and ECP were *"at loggerheads over turf":* HR thought non-safety employee issues were their business whereas ECP believed employees should be able to take any issues to them. ECP and HR people didn't even know who each other were. ECP and ECOP were suspicious of each other. Grise spent the next five or six months nearly full-time at Millstone. She brought tremendous *"sagacity"* and clout with headquarters. She instilled a sense of urgency in HR, established a structure of listing outstanding items, identifying an owner for each, and getting status reports. She built a business partner concept with the line organization by assigning someone from HR to sit at each unit. Grise articulated the need for cooperation among HR, ECP, and ECOP to serve the common good and to *"be glad an issue gets into the system."* She engaged them in teambuilding activities including weekly meetings. Grise was also the best person to talk to Billie Garde, who was a barometer for Little Harbor issues.

Training for managers and supervisors in SCWE began in the summer of 1997. As Paul Blanch said, *"training is #1 to prevent retaliation."* Blanch believes that retaliation occurs when people don't understand each other. For example, a worker brings a problem to his or her supervisor, and the supervisor thinks they responded adequately. They later find out that the worker went to the press or to the NRC. The supervisor is likely to feel negative toward the worker, and maybe six months later their performance evaluation suffers—it's *"human nature."* Supervisors also had to be convinced that they were judged on their response to problems, not their lack of problems. The nuclear culture is that *"good supervisors don't have problems"* and therefore problems are suppressed. The supervisors who don't know they have problems or know and do nothing, are the ones that got low grades.

In October, Bruce Kenyon insisted on more detailed SCWE training for all managers to be completed by the end of the year. An outside law firm provided three attorneys who helped develop and deliver the training, and also provided advice to management on SCWE issues. Through December 1997, 475 Millstone managers and supervisors went through specialized SCWE training. The training was based around a series of case studies of actual situations from other sites, and Little Harbor and NRC personnel sat in and gave feedback. The key to training was for the supervisor or manager to take the right first few steps to stabilize the situation, diagnose if there was a problem, and then get help. This was deliberately analogous to training for reactor operators where the first few steps in an emergency are memorized, after which they go to written procedures and get more help, systematically proceeding to a safe condition and then resolution of underlying problems.

Senior management kept providing visible support for SWCE training. At an offsite management retreat in January 1998, senior managers participated in a role-play in front of a large audience of managers. Mike Brothers played a manager who had not listened to his subordinate, played by Bruce Kenyon's assistant Neil Bergh. Even NU CEO Mike Morris had a role. In a mock trial setting, Chuck Thebaud, one of the outside lawyers, represented Brothers, Billie Garde represented the employee, and George Edgar, another of the outside lawyers, played the judge.

In January and February of 1998, there were some small events that were poorly handled by supervisors but rescued by the People Team (Bergh et al., 1998). Reviews suggested that these events involved managers who were new to Millstone and had not yet had the SCWE training. This revealed some vulnerability in the organization. Mike Gentry suggested an approach from his experience as a Boy Scout leader—a "Quick Start" 45-minute video that every new supervisor or manager had to see upon being hired, with a requirement of full training within 90 days.

An important enabler of improvement was the establishment of criteria and tools for measuring progress and detecting problems. Initially, Little Harbor and NNECO moved separately to outline criteria. Little Harbor had identified 12 characteristics of a healthy safety culture in early 1997, and proceeded to use a five-category evaluation scale for each characteristic, rated red (unsatisfactory), minus yellow, yellow, plus yellow, or green (world class). Each also had an up arrow (improving), horizontal arrow (holding), or a down arrow (declining). Little Harbor decided that the criterion for restart consideration was neutral yellow or better, with steady or improving performance, in every category (Beck, Griffin, & Garde, 1998). Periodic assessments were conducted by reviewing documents and conducting structured interviews with employees. The first set of interviews was conducted in June and July of 1997, with the first performance review in December. The April 1998 review rated the safety conscious work environment sufficiently improved in all categories to warrant consideration for restart. The NRC Staff agreed. On May 19 the Commissioners accepted these recommendations and approved reclassification of Unit 3 to category 2, which allowed restart when the NRC Staff was satisfied that all requirements had been met. In the same time frame, Millstone management, Millstone Oversight, ECOP, and the Nuclear Committee Advisory Team each formally certified that Millstone had improved its work culture sufficiently to justify restarting Unit 3. On June 29, the NRC issued a letter authorizing restart of Unit 3, which began producing power on July 4, 1998.

The overall intent of regulatory action was that Millstone be able to manage its own work environment. In October 1997, Millstone established success criteria for SCWE as part of their comprehensive plan (cross-checked against Little Harbor's criteria): (1) employees are willing to raise concerns, (2) management is responsive, (3) ECP is a viable and trusted alternative, and (4) management has the ability to recognize and react appropriately to emerging situations. NRC accepted this plan in December as the first demonstration that Millstone could measure their own progress. Millstone developed Key Performance Indicators for these four criteria, initially over 30 but later reduced to 12. The Corrective Action Program was a key to dealing with issues—it had objective, visible steps that demonstrated to employees and regulators that Millstone management could be responsive and get results. Regular surveys were taken of employees: a leadership survey about relationships with supervisors and managers, and a culture survey about the work environment. Additional informal information was regularly available in meetings such as the People Team where SCWE was a topic of conversation. ECP had its own indicators, including number of concerns, proportion of concerns with requests for confidentiality (indicating fear of retaliation), proportion of concerns relating to harassment, intimidation, retaliation, and discrimination, proportion relating to safety, number of concerns substantiated by investigation, time to investigate and reply to the concernee, proportion of concernees who said they would use ECP again, and number of NRC allegations. ECOP developed a very effective survey methodology that averaged 95% participation. One-half of the respondents were from Focus Areas that were showing signals of problems, and one-half were a random sample of employees. A core group of about 50 employees known only to one person on ECOP answered the survey every quarter to give a comparable measure of progress. ECOP also conducted focus group interviews in *"hot spots"* where potential issues were emerging.

But the changes at Millstone were not solely in management or from management. Workers live in communities that can make them embarrassed or angry about working for Millstone. At first, when newspapers would *"hammer on"* Millstone, employees saw it as management's problem. Indeed, management was working hard to communicate their plans and progress to the media and the public. Bruce Kenyon said to employees during an all-hands meeting, *"when are you going to say what you think?"* An ad hoc employee support group formed in late 1997 and collected over 1500 signatures on a petition stating their support for Millstone. Members of the group began attending public meetings, writing to newspapers, and generally providing a public voice for Millstone employees in support of management. This contributed greatly to the sense that Millstone was a single community, and reinforced other efforts. As one respondent said, "*I'll never forget the words of Susan Perry Luxton* (a community leader critical of Millstone) *when she told the NRC that she trusts NU management*."

Consolidating Successes and Facing the Future

Following the restart of Unit 3, Millstone activity shifted somewhat from the intensity and crisis mentality of the "recovery" orientation to the long term process of stabilizing the organization, sustaining progress, and ensuring the success of the company in a rapidly-changing environment. In 1998, Millstone was far from stability: Unit 2 would require many more months of work in order to restart, Unit 3 was behind in planning a refueling outage to take place in less than a year, Unit 1 was being decommissioned, and the utility was still facing economic uncertainty. Millstone has to be put up for auction by the end of 2003 as part of the deregulation process in Connecticut. NU management began planning that the auction would take place considerably sooner (it is currently planned for early 2001).

NNECO moved to reorganize Millstone management because key positions still were being filled by temporary recovery managers and consultants. Workers did not always respond well to temporary managers and there were far more managers than an operating station should need. Lee Olivier was hired as the new VP Nuclear for Millstone, and Bruce Kenyon was promoted to President of Power Generation for NU. Olivier arrived just in time for the start of a complete top-down management reorganization at Millstone, beginning with Vice Presidents, then Directors, then managers, and finally supervisors. This reorganization cascade was carried out through the manager level by naming new managers, but many of the changes could not be made for many months due to the pressure of current work duties, and the supervisory selection was postponed until after the restart of Unit 2 and the refueling outage of Unit 3, both in the first half of 1999.

The reorganization moved Dave Amerine to VP Engineering, the post he was initially hired to fill. VP of Human Services, a post reporting to Bruce Kenyon, was taken by John Carlin, a newcomer to Millstone. He was now the third Vice President on site to have run SCWE, which has embedded these principles deeply into top management. The oversight and licensing organizations were both placed under Ray Necci, promoted from Engineering. Ed Morgan had left earlier in the year, and the new ECP manager was reporting to John Carlin. It seemed as though since early 1998 *"there was a new organization chart every month."* Achieving a stable organization is necessary to build durable relationships between workers and managers. At this point, many of the agreements that were reached between workers and managers had to be renewed or renegotiated with new parties.

Many of the SCWE and ECP functions are expected to transition gradually to HR. The demands for these functions should diminish as line managers become more effective. ECP will focus increasingly on nuclear safety significant issues, as occurs at other utilities. ECOP has been trimmed and a complete turnover of membership has occurred. Its mission was rewritten, and it now reports to Lee Olivier rather than to Bruce Kenyon. Little Harbor ceased being the independent third party oversight organization in March 1999, and has now been hired as a consultant to give periodic reviews of Millstone's work environment.

Significant challenges remain for Millstone Station. All but a few hundred contractors are being released by the end of 1999, down from a peak of nearly 3000, and there is a resulting upswing in concerns to the ECP and the NRC. Millstone has a workforce with a strong sense of *"entitlement"* that their jobs are secure and they are very aware of their rights. People know that one way to attempt to keep their jobs is to engage in protected activity, i.e., to lodge a concern. Negative actions can be expected to produce complaints, which have to be investigated properly. One senior manager reports that *"I spend 60 to 70 hours per month answering investigations of unsubstantiated concerns filed against me."* The Millstone workforce recognize that they are faced with downsizing by at least one-third in the next year, and possibly below that. Despite promises from management that there will be no involuntary severances, there will be great difficulty meeting these conflicting demands and resultant potential for more unrest.

But many interviewees talk about having *"swung the pendulum"* from management dominance to employee power. As one said, it was the *"Most severe pendulum effect I've seen."* Some managers are under a *"reverse chilling effect"* in which they *"feel they are held captive."* The culture is not yet healthy enough to consistently find the balance between the needs of the company to require performance and the needs of individuals. There are still *"too many non-performers… The same core group of people are relied on to do more than their share, and they are in danger of burnout."* Early on, management felt they could not hold people accountable. But, "*SCWE is not anarchy*…[Managers] *can still discipline people involved in protected activity… You're not an island. If an employee is dissatisfied, you've got help*." Many managers have figured it out, and the openness in the culture allows them to discuss issues with employees in a factual and caring way. Yet other employees complain that the reorganization has sidetracked some of the best leaders of change and put back in authority some of those associated with the old Millstone failures. Conflicts are not only between managers and workers, but also peer to peer and group to group. *"People want apologies from those who accused them before." "A lot of healing is needed… not just trust…rebuild relationships…reintroduce humanity."*

The work environment has changed dramatically, but it is still fragile. Several interviewees mention that *"people are laughing more"* and that this is a dramatic sign in comparison to the past. In their first report as consultants to NNECO in July 1999, Little Harbor described the safety conscious work environment as "essentially where it was… Some areas have improved while others have slipped." Although "Millstone management is sincerely dedicated to maintaining a safety conscious work environment… [there was] a desire to return to normalcy a bit sooner than circumstances at the site warranted" (Little Harbor Consultants, 1999, p. 8). Management responded with various actions to be taken, and Little Harbor will return in a few months to assess SCWE and management's implementation of improvements.

The NRC has again undergone tremendous change. There is a new Chairman of the Commission. Staff downsizing has hit hard. The NRC has shifted to more self-regulation by plants and a new set of criteria for classifying the amount of regulatory attention to be given to plants. Although in 1998 it seemed that Millstone's SCWE efforts would mark a new standard for the nuclear power industry, amid rumors that the NRC would put third party oversight on other sites, it now seems that this will not be the case. Millstone may be a model for other extreme cases, but will not set a pattern for the regulatory process. In this *"first of a kind Order…we learned… insights we shared with our staff… The Commission and staff concluded we have the tools already to deal in this arena, but we have to be sure we are effective… We hope we don't have to do it again, but we're able to."* The NRC does not currently intend to use SCWE as an indicator of performance, relying instead on more typical objective measures of performance such as reactor trips and other events. However, the industry has watched Millstone closely to understand its lessons for leadership and culture change as well as regulatory relationships.

Analysis

There is no single theme underlying the changes at Millstone Station and no one leader whose vision propelled organizational transformations. Bruce Kenyon brought personal credibility, the courage to restructure the senior management team, a clear set of values congruent with the needs of the Station, and a commitment to two-way communication. But the shape of the changes and the way they unfolded were improvised by scores of leaders throughout the organization. As one manager said, Kenyon "*went along with all my recommendations. He didn't always agree*…[Sometimes he] *swallowed hard*." Dave Goebel and Ed Morgan reshaped ECP. Mike Brothers and Dave Amerine guided SCWE, ERB, and the People Team. Judy Gorski and Cheryl Grise rebuilt HR. Senior management created the conditions for successful improvisation by remaining visibly committed to their goals, keeping open lines of communication and feedback, creating multiple opportunities for broad participation, permitting themselves to have doubt (Schulman, 1993) about how to accomplish their goals, and therefore seeking ideas and help from employees, prior concernees such as Paul Blanch, outside consultants, other utilities, Little Harbor, NRC, INPO, and many other sources.

The changes at Millstone Station could not simply be planned and communicated. There were no existing rules, guidelines, or precedents to help set the course. Over time, as people learned by doing, the understanding of what was needed to succeed shifted from vague ideas about trust and an effective Employee Concerns Program to comprehensive ideas about a Safety Conscious Work Environment and its connection to structures and programs. It was not enough to communicate in a caring fashion; there needed to be mechanisms to deal with crises and conflicts, and there needed to be functional work management, corrective action, and oversight in order to convince the workforce and the regulators that Millstone could correct its problems. These were based on training in people management and performance management, as well as the special demands of a wounded nuclear organization.

Because senior management had created spaces for participation, there were many eyes and ears watching the organization move forward, stumble, and try again. Many individuals stepped up at key moments to offer the components from which to fashion change, whether it was the ERB function, ECOP surveys, People Team rapid response flowcharts, training elements, legal advice, employee support group, senior leadership, etc. An organization in crisis needs to draw on many resources, and you can never predict how many you will need. Millstone needed multiple places to address worker concerns, new management skills, willingness to invest time and money in people as well as technical improvements, effective programs and support groups such as HR, and diversity of perspectives. Insiders and outsiders, technical experts and people experts, operators and engineers, managers and workers, needed to respect each others' contributions and build effective working relationships.

"Foundational learning takes a while." The learning *"has to be tested; the learning is in the test."* Those tests included crises such as the Training and MOV events as well as Focus Area conflicts and individual concerns filed with ECP. The learning was not in the policy and the structures but in the behaviors that made the structures come to life. SCWE became *"rooted"* in the personal learning of senior managers such as Mike Brothers and Dave Amerine who allowed themselves to be transformed by their commitments. The theme arose again and again that doing the job changed people—senior managers, ECOP members, Little Harbor members, and others who grew into the requirements of the job, supported by a system that encouraged them to grow rather than blaming them for problems. These challenges not only changed those who dealt directly with them, but also the employees whose evaluations of these "tests" determined the success or failure of Millstone Station. They watched carefully to see how management reacted to these defining moments, weighing the differences between words and deeds, between paper promises and real change. The initial tests were necessary near-failures, but management admitted its mistakes, kept the lines of communication open, sought lessons for improvement, and tried again. Over

time, people learned to deal with crises and chronic problems, and they learned that they were capable of change and that change was welcome.

This is not the end of the journey. Millstone Station, along with the rest of the nuclear power industry, faces deep challenges in the next few years. The memories of mistrust and the feelings of hurt can still be engaged by new situations. The work environment and the performance successes are fragile, and many people have given about all they can give. It is important for Millstone Station and other work settings to understand the lessons in their journey, and we hope this paper has captured some of them.

Notes

1 The NRC later acknowledged lacking objective criteria for placing plants on the Watch List (Jackson, 1998). Under its new, more objective criteria, Unit 3 would not have been subject to increased regulatory response (NRC, 1999).

2 The investigation of Three Mile Island (Kemeny et al., 1979) identified the need to exchange operating information and led to the founding of an industry association, the Institute of Nuclear Power Operators (INPO, see Rees, 1994) in part for that purpose. Similarly, the reports on Chernobyl by the International Atomic Energy Agency (1991) brought the concept of "safety culture" into the industry and led to the creation of the World Association of Nuclear Operators on the INPO model.

3 For example, several key contributors are now working at Alyeska, the Alaska oil pipeline company, and many have been asked to present the Millstone story to various organizations (e.g., Amerine, 1999).

4 Quotations in italics come from our interviews. In general, we have not identified the source by name.

5 Philadelphia Electric Company, Virginia Electric Power Company, and Carolina Power and Light assisted Units 1, 2, and 3, respectively.

Acknowledgement

We would like to thank Bruce Kenyon and the other interviewees for their cooperation, candor, and appreciation for the importance of sharing the lessons from these challenging events. This research was supported by a Marvin Bower Fellowship at the Harvard Business School.

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CHAPTER THIRTEEN

The Human Contribution to Overall Performance in Electricité de France

ARMAND COLAS

The European Directive adopted on February 19, 1999, noticeably opened up the European electricity market. Personnel training and the beliefs and values of society have changed. Experience-based feedback is well-suited to such developments. Finally, progress itself has led to constant questioning. The nuclear industry specified the content of a policy based on human factors in 1995/1996. Later, a safety management doctrine was completed and clarified. Electricité de France is now involved in work on a "quality policy" dedicated to considering all aspects of progress, security, safety, and performance activities through appropriate management. External approaches in risk sectors, some basic studies and works, provide a basis for guiding both reflection and the action programs. This chapter discusses some of these aspects.

Following a new European Economic Community regulation, Electricité de France (EDF) has increasingly entered the free electricity market. Until now, EDF had been applying the production and distribution costs to consumers. Experience-based feedback has provided lessons for improving safety that deal with preventing the consequences of nuclear accidents involving people and the environment. Now, after about twenty years of operating experience, it is evident that to the extent that all aspects of the nuclear plant and equipment are operating in good order, a possible severe accident is quite unlikely. Preventive activities and safeguards provide a safe response to human errors. Such activities and safeguards require a focus on maintenance, testing, calibration, and malfunctioning.

On the other hand, public acceptance is more and more becoming a real threat to the continuation of nuclear power generation. More reactors and installations have been closed as a result of high production costs and public opinion than as a result of actual accidents. The public regards the nuclear power industry as having a high level of professionalism, providing quality service, and having acceptable levels of reliability. People do not understand that one can make a mistake in one's train of thought, in using controls, or by forgetting something that looks simple or that one can make "normal life" mistakes while carrying out nuclear activities. The nuclear power industry is accepted according to the subjective and emotional image it shows to the outside world. This consideration necessitates that the industry pay attention to new requirements that evidently arise from experience-based feedback during operations.

At the same time, experience has increased, and the public has also become more and more experienced in nuclear-related issues. The social culture has changed, too. Young people do not have the same demands and hopes about their jobs as previous generations did. They very much want to understand, to be involved, to participate. Past generations accepted more discipline, efforts, and so on, whereas new generations want more respect, consideration, and personal involvement. They do not want to be considered a kind of robot that just applies procedures and predefined actions.

Experience-based feedback can provide many lessons that are increasingly focused on the way jobs are performed. The development of exchanges between operators at the international level provides others with lessons and experiences. Whether nuclear-powered or not, EDF must be more and more open to all these issues. And it must integrate all of them into a general philosophy of thinking and managing. One of the first steps taken in EDF toward this goal was the human factors policy, in which we attempted to integrate internal experience-based feedback and external tendencies. Another step was the renewal of safety management. EDF has deepened its involvement in another level of integration based on "quality management," which includes specific management aspects, error prevention, leadership, and human performance. In what follows I attempt to give the background and main features of these different aspects.

ALL ORGANIZATIONS MUST ADAPT TO FACTORS OF CHANGE

Companies are continuously required to change. This observation is true in a general way because the world constantly changes, both inside and outside any given company. But the requisite to change is even stronger when the company must deal with only one market each time. Consumers decide what they want and what they like. Some people claim that "customers are like kings." In reality, the situation is probably even more pronounced: "customers are free."

In general, four major factors bring about change: (a) the company's business climate and, in particular, trends in the market where it sells its products and services; (b) societal factors in general, such as customs, new needs, changes in the regulatory environment, and a better understanding of human processes; (c) changes to production facilities, either to keep pace with market trends or as a result of aging or obsolete equipment; and (d) internal factors, primarily due to "progress drivers," which are a response to both competitive pressures and an internal dynamic based on experience-based feedback. These factors generally confirm that progress is possible and desired.

EDF AND THE NEW BUSINESS CLIMATE

EDF has enjoyed a virtual monopoly on the generation and distribution of electric power in France until now. This situation changed on February 19, 1999, with the liberalization of the electricity supply market in Europe. It should be noted that electricity consumption levels depend largely on how electricity stacks up against other sources of energy. EDF has always felt competitive pressure, which means that the current situation is not entirely new. Over the last few years, EDF has implemented a policy designed initially to stabilize costs, followed more recently by a cost reduction program. The sales price of electricity has dropped by 20% in inflation-adjusted terms over the past ten years.

The above arguments are defended fiercely within the company. Nevertheless, there is a world of difference between supplying electricity when the grid requires it, and hence selling it at a price that is as low as reasonably achievable, and competing on markets to supply electricity, and therefore selling it at a price dictated by the law of supply and demand. EDF's work force still has a long way to go before it fully accepts this cultural change. By way of analogy—with particular significance for the French: there is a major difference between being a decent soccer player and being good enough to compete in the World Cup (though we recently demonstrated that we are capable of major feats in this field, too!).

Public opinion also has forced EDF to improve its plant operations. Incidents during the summer of 1998 led to heated internal reactions. These incidents included used fuel containers with external contamination, slight contamination found on clothing in homes, traces of contamination on roads of sites not located in protected areas, and slightly contaminated materials found outside plants. These incidents gave rise to media coverage, pressing questions from the Safety Authority, and a significant decline in the public's previously favorable opinion of nuclear power. It became clear that nuclear power could indeed become vulnerable. Three major threats to the continued generation of nuclear power have since emerged:

1 The first threat is the public's opinion of nuclear power, which has a complex interrelationship with the media and public authorities. Subjective and tending toward generalizations, this opinion echoes certain deep-rooted fears of the harmfulness of nuclear power, which is in fact a product of technology invented by humankind. Disconnected

from real dangers or rational economic and political decisions (such as choice of an energy policy), public opinion instead stems from fear. The French want to sleep in peace, not threatened by random atoms.

2 Dangers resulting from risks and the ability of the utilities to control such risks pose the second kind of threat. Nuclear power is considered to be a possible danger to the health of operating personnel, residents living in the vicinity of sites, and the environment. The possibility of a nuclear accident is by no means new and is at the heart of all basic safety principles.

3 Another major threat is the idea that nuclear power is not competitive with other forms of energy, which means that it is inevitably doomed to failure. This idea was underscored by the closure of the Creys-Malville site, despite the fact that everyone thinks it was a symbolic political maneuver to please environmentalists.

THE IMPACT OF CHANGING CUSTOMS, REGULATIONS, AND KNOW-HOW

A few years ago the workweek was reduced from 40 hours to 38 hours. The recent introduction of the 35-hour workweek in France, coupled with EDF's announced intention to move toward a 32-hour workweek, means that a number of new constraints have arisen.

The changeover from 35 to 32 hours will lead to organizational changes with consequences that cannot be clearly seen or taken into account at present. A large portion of the capacities of operating staff capabilities comes from a long, sustained "apprenticeship" process. A reduction in the time spent at the controls may lead to a drop in capabilities. This reduction in work hours will also increase the number of employees to be qualified, which in turn increases initial training expenses. If this decrease in on-the-job training is shown to reduce staff capabilities for very demanding activities, simulator training will have to be reinforced, which would lead to new expenses and new constraints. EDF has yet to evaluate this type of change. An accurate analysis should be carried out.

Another important aspect is new customs and new needs. As educational levels rise, and with increasing safety requirements in plant operations, EDF is recruiting personnel with an ever-higher level of qualifications. At the same time, the social environment is becoming more open than in the past, and employees are increasingly encouraged to voice their ideas. A few years ago, good operating personnel were expected to do exactly what they were told. Nowadays, companies must deal with employees who want to put their own knowledge, skills, and intelligence to use.

In January 1999, Benoît Journé presented a dissertation in which he contrasted the predefined, Taylor-style approach of Charles Perrow (1984) with a more constructivist method that is intended to reconstruct safety in real time according to the changing situation (in reference to the Berkeley School; see Rochlin, LaPorte, Roberts, & Weick, 1987).

Perrow's approach, however, does not offer an all-encompassing vision of technical and human systems and illustrates how complexity can, in part at least, be offset by an organizational system and predefined tasks. Yet it also portrays a rigid system, which in some ways is not appropriate for assimilating events or facts that may require a change in the system.

The approach based on high-reliability systems, which comes from the Berkeley School, focuses on the fact that in a carefully demarcated world a group of people can be capable of building an appropriate and flexible, yet solid, response. Journé (1999) showed how knowledge (in the cognitive sense) of the state of a system can be developed on the basis of disparate existing components (e.g., knowledge and experience of the different protagonists, input from formal rules and procedures, contents of certain documents). He also showed how sense-making at the meta-intelligence level can guide players in an optimum manner toward the most efficient mental processes in their diagnostic analysis and search for solutions. This "real-time construction," however, depends on the following conditions and features:

1 Competencies are adapted to the scope of operations or problem area to which the participants must respond.
2 The volume of mental demands is compatible with the mental capacities of the entire human system; this consideration includes the interactive processes required for dealing with problems in real time.
3 A form of consonant agreement among participants makes it possible not only to combine the elements each of them contributes but also to stimulate and revive knowledge, creating a dynamic verging on "coactive" apprenticeship. Journé underscored the important role played by novices, who ask questions that each experienced player is supposed to be able to answer but that sometimes—indeed often—raise difficulties or doubts.
4 Another condition is a climate that allows this structure to function, that is to say, an atmosphere that is conducive to the expression of competencies, without any notion of precedence or psychological complexes, without any restrictions set, and without a desire on the part of individual participants to monopolize the "stage" where collective competencies[1] are being expressed.

Together, these data set out a relatively clear management problem: If safety is significantly determined in this way, how can this type of system be optimized?

In demonstrating the limitations of Perrow's approach, Journé provided a number of key points for improved understanding of what can only be gained by being predefined through a theoretical analysis. In real time it is not actually possible for players to embrace "the entire problem area." This situation gives rise to a vision with a predefined framework, which organizes a multitude of free areas in which players can act constructively.

Lastly, it is important to note that under no circumstances should this real-time construction lead to unbridled improvisation (an idea that horrifies advocates of Taylorism). Even when undertaken as a real-time process, analysis and decision-making must meet the reliability standards required of human activities.

Theoretically, Taylor-style management, whereby virtually everything is predefined and laid out, should be replaced by a management method based on real-time reactions and coaching to optimize the expression of core competencies. These work methods guarantee that what is developed as a real-time response subsequently has its intended effect in actual conditions and that work methods are consistent with the prerequisites for high reliability of human activities. This operating mode requires the introduction of an active defense-in-depth system and the application of principles of professionalism. In keeping with the principles of professionalism that were defined by EDF several years ago, we at EDF have a rough idea of what we are aiming for.[2] Management practices must now be defined in order to attain our goals. Some U.S. companies and the Institute for Nuclear Power Operations (INPO) have defined a framework for human performance programs. EDF has launched a relatively limited human factors policy, but the issue now is to activate this policy.

CHANGES DUE TO TECHNOLOGY AND CHANGES IN PRODUCTION FACILITIES

There are two major types of change in this category: (a) a new generation of control rooms, integrating the development of computer control systems, and (b) technical changes that are relatively limited in scope and mainly related to the introduction of new equipment (often computerized) and technical modifications to plants.

Considerable research has been conducted since 1984 on the design of computerized control rooms. EDF is currently in the final assessment and feedback stage after building four units at the Chooz and Civaux sites. Start-up tests are being finalized at these two sites before operations begin. A definitive evaluation can only be made after a long operating period. Because advances in equipment and information technology systems are being made at a fast pace, EDF is already working on a new generation of computer interfaces, as part of its research and development initiatives, to be applied to a new reactor if one is built. The large majority of the new tools implemented on-site are studied from an ergonomic point of view, in light of the users' needs, before these tools are actually put into operation. This case is particularly true for new computerized systems. It should be noted, however, that requests for approving the ergonomics of these new tools are always submitted late. This practice often leads to long, costly changes just as the product was almost ready to be brought into operation. In addition, certain defects can no longer be remedied, for this step would involve reviewing basic choices made solely on the basis of technical and software factors. Unlike in other companies and sectors, ergonomic factors and users' needs are not systematically taken into account from the outset in engineering projects. Recently, this circumstance caused problems on one site when major technical changes and procedures were implemented. In addition, a number of projects nearing completion were abandoned when operating conditions were found to be incompatible with what was possible in a real-life, on-site situation. We currently are studying the systematic integration of human factors (e.g., ergonomics, users' needs, impact on work conditions) from the beginning of the design of new processes or plant changes.

THE PROGRESS PROCESS

In 1982 EDF started to pursue a structured, experienced-based feedback process with the creation of its first Human Factors Team. The first database was set up in 1984, and EDF has been using a very sophisticated human factors database since 1993. The major problems arising from human factors were already pointed out in the 1990s: More than 50% of failures identified in significant incidents were related to individual or collective judgments (operating choices or decisions, individually or in teams). EDF therefore is no different from other French companies operating in high-risk sectors, all of which find that most problems encountered are in day-to-day, routine operations involving skilled, motivated personnel. This finding was subsequently supported by the database, which led EDF to conduct studies in 1991 on the definition of professionalism. Also around this time the International Atomic Energy Agency published its INSAG-4 report on safety culture (International Nuclear Safety Advisory Group, 1991). These two factors encouraged EDF to define new activities to develop a self-questioning attitude in teams, to encourage professionalism, and to implement a defense-in-depth initiative for human activities. EDF has since sought to favor long-term, in-depth actions rather than case-by-case reactions, which involved applying corrective measures to resolve each problem. This strategy was adopted around the same time as the INPO's studies in the United States on professionalism, leadership, the search for excellence, and human performance. EDF contributed its own experiences and ideas to the U.S. study. Today, EDF's analysis indicates that the utilities were not able to take a sufficiently broad, deep approach to dealing with changes. The "Producer's Managerial Project" currently being defined should meet these conditions more effectively than past approaches have.

WELL-MANAGED CHANGES SATISFY INTERNAL AND EXTERNAL FACTORS THAT DRIVE CHANGE

Major guidelines on safety, performance (particularly in light of liberalization of the European market), quality, management, human factors, and so on are the result of all these parameters. Human factor issues are outlined in a human factors policy, which is summarized below.

Foundations of the Human Factors Policy

To establish the main thrust of its commitments, EDF's Nuclear Power Plant Operations drew on the analysis of its experience since the beginning of French nuclear power plant operations in the late 1970s. In particular, it restated the recent basic human reliability data obtained in the field, which gave failure rates in a range from 10^{-4} to 10^{-5} (supplemented by other evaluations). It emphasized (without being able to give any values, at least for the moment) that the human factor brings a permanent added value to safety through an ability to recover situations as well as through its inevitable complementing and adaptation of safety instructions and specifications. The concept of "human unreliability" should thus be seen in relative terms, and, to a certain extent, false images of the situation should even be corrected. This work therefore intuitively anticipated the findings of Journé.

However, Nuclear Power Plant Operations stated that the entire company (managers, safety specialists, human factors specialists, field supervisors, and operational staff) is convinced that there is still much room for progress, which would be welcomed across the board, including operational staff, who are the first to be affected by inadequacies in the management of situations.

Taking a step back from its own experience, Nuclear Power Plant Operations stated that until now, like the majority of industries in which risks are involved, it has mainly relied on measures that are "external to the individual" (organization, regulations, requirements, quality assurance, procedures, man-machine interfaces, etc.). Yet the majority of weaknesses that currently remain relate to the following personal or collective work methods and precautions: (a) making preparations before taking action, in order to enable each individual to build up a clear picture of what he or she is to do (risks, difficulties, protective measures planned in advance, etc.); (b) correctly carrying out the various tasks during work performance, such as obtaining information, targeting individual attention, cross-checking situational data, practicing self-checking, and obtaining access to independent monitoring; (c) ensuring the situation is clear after carrying out the activity by providing information, reporting, and ensuring demobilization and cleanness of work sites as well as ability to trace operations; (d) taking responsibility for the whole activity, managing interferences and interactions with other actors, coordinating, informing others, practicing safe exchanges of information, and so on; (e) actively participating in detection and correction of defects and noncompliance with quality standards, that is, becoming a dynamic actor in this field; and (f) improving ability to recognize personal weaknesses, particularly in relying on memory, making diagnoses, targeting attention, organizing tasks (difficulty of parallel tasks), and harboring "false certainties."

Solutions to EDF's specific requirements can be found in the actions implemented by other nuclear power operators (in the United States, Japan, Sweden, Belgium, etc.) and in measures taken in other sectors (civil aviation, air traffic control, nuclear submarines, etc.). On the whole, in other sectors standards of professionalism are expressed much more clearly and precisely than in the nuclear power industry, and they are anchored in institutionalized methods and practices. Civil aviation standards provide a good example: These standards include checklists, cross-checking in the cockpit, over-the-air announcements of ground approach data, and strict communication standards. The methods advocated in the United States and other countries, such as three-way communication, STAR ("Stop, Think, Act, Review"), STARC ("STAR plus Communication"), and QV&V ("Qualified, Verified & Validated"), are also good examples. It is unfortunate, however, that these methods, which should remain flexible, adaptable, and intelligent (in accordance with the findings of Journé, 1999), tend to become formalized and imposed as rules. EDF, which as yet has embraced few of these methods, faces the challenge of ensuring that these practices, which nowadays are unavoidable, are irreproachable yet, at the same time, remain capable of accommodating the "intelligence of the situation." This balance has almost been achieved for EDF's technical specifications (a set of precise operational rules governing safety), showing that striking such a balance is possible. This experience leads us at Nuclear Power Plant Operations to believe that we should adopt a similar approach, which implies years of education while patiently but unrelentingly pursuing our goal.

Because most of the weaknesses are a matter of individual and collective judgment, efforts at the grass-roots level must constitute the focus for the main thrust of the policy. Nuclear Power Plant Operations is keen to stress most strongly that, with such an approach, it is not possible to make rapid progress in all areas. A typical program would involve implementation of in-depth actions in the medium and long terms. Nuclear Power Plant Operations emphasizes that the risk of proliferation of corrective measures and activism, which would only confuse and limit the efficiency of actions, is not appropriate with this approach. On the other hand, it is acknowledged that, as evidence has shown, if a particular event were to throw up problems that can be rapidly corrected with a high probability of success, there is no reason for not doing so. However, any immediate actions must be relevant and limited in scope. Nuclear Power Plant Operations wishes to avoid any obligation to commit to a comprehensive action plan to correct all human causes following every incident.

Resources in Terms of Human Factors Specialists

All sites have now appointed "human factors correspondents." They are responsible for drawing up or supervising human factors aspects involved in incident analysis, producing analysis summaries that show the site-specific error categories, and outlining priority actions for the site. Their responsibilities also include the provision of competent assistance to site management and line management in undertaking programs or activities, participation in such programs or activities where necessary, the monitoring and assessment of these programs or activities, and provision of assistance to the site in all areas related to human factors.

The national Human Factors Team is made up of nine people from different backgrounds. Its mission is to consolidate and enhance at national level the results of analyses of human factor causes, to carry out subject studies enabling progress to be made, to provide assistance to sites in terms of skills and resources (in particular to the human factors correspondents at each site), and, in broader terms, to develop human factors skills throughout nuclear power plant operations (e.g., through training programs), to promote human factors actions within Nuclear Power Plant Operations policy, and to organize the sharing of experiments conducted at the different sites. In order to facilitate the exchange of experiences (which are a key factor in this area) and maintain the impetus of the approach, all human factors specialists are part of a network that is managed by the national Human Factors Team.

Development of Human Factors Experience-Based Feedback, Involvement of Actors, Collective Self-Diagnosis

The activities that form the basis of Nuclear Power Plant Operations' human factors policy have been tested at selected pilot sites on the basis of projects prepared by the sites themselves, largely in cooperation with the Nuclear Power Plant Operations' Human Factors Group. Although there are a number of different approaches, they all comply with the following principles:

1 The work consists of a self-examination and analysis of the operating practices and modalities of operational work groups.
2 The work is carried out with the involvement of management, which is able to solve any problems that arise. Line management directly responsible for the team concerned is most frequently involved.
3 The low-level (or operational) staff involved in the experiment are asked to become involved in looking for weaknesses (as well as

strengths), choosing the most appropriate solutions, and taking responsibility for implementing the solutions that concern them.

4 Although some solutions are implemented by management, others necessarily involve all team members and lead to changes in practices or behaviors, which operational staff personally undertake to implement.
5 The activities are followed up, if necessary, with a new work meeting that is held in order to review the situation and relaunch or refocus activities.
6 The work is part of an ongoing practice, although the modalities may change to take account of changes in the situation. The aim is to create a climate of continuous questioning in relation to errors requiring correction, good practices to be developed, areas of potential progress, and progress made within the team (safety, performance, and job satisfaction). Such a process necessitates periodic work meetings, accompanied by continuity of action between meetings.

The different sources of error from within the team, at site level, or at the level of nuclear power plant operations (i.e., the national level) all have potential for selection as areas of improvement. Priorities can be defined at Nuclear Power Plant Operations management level, site management level, and department management level. Each team incorporates these priorities but must also define its own priorities as a function of its specific characteristics and the situations that it encounters.

CONCLUSION AND COMMENTS

When we at EDF compared EDF's approach with approaches taken in the United States and other countries or approaches taken in other sectors, such as civil aviation, we came to the conclusion that we have achieved a good level of analysis and quite a good perception of what we need to do. The issue now is our capability to implement this kind of action on the ground. It appears that we first must develop a "management culture," which mainly requires developing our understanding and sensitivity in the field of "soft skills." Hard skills concern techniques, processes, operations and maintenance, how to organize in an explicit way, how to design safety regulations, and so on. Soft skills are related to the subjective, emotional aspects of human factors, aspects that interfere with communication, management, interpersonal relationships, social atmosphere, true leadership, conviction, how to obtain adhesion, and how to sustain progress. In the field of soft skills the limits of rational approaches quickly become evident. We can bring about a human factors culture, quality culture, and management culture that are deeply integrated into ways of thinking and ways of acting in the daily routine. These cultures make up the new field that we must now develop and consolidate.

Notes

1 A reference to the work of Guy Jobert (1998), Université de Dauphine, Paris, which shows that individual and collective identities are forged largely on the public “stage” created by work participants, who often tend to “perform.”

2 These principles are similar to the Institute for Nuclear Power Operations’ “principles for enhancing professionalism.” EDF took part in defining these principles by providing analyses that had already been made at this stage.

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CHAPTER FOURTEEN
Event Analysis as a Tool to Enhance Safety Culture in Nuclear Power Plants

BABETTE FAHLBRUCH

An important aspect of safety culture is its holistic approach comprising all levels of an organization as well as the relevant extra-organizational environment. How an organization learns from its experience is a safety-critical feature and an expression of its culture. Therefore, an event analysis methodology should investigate all levels of the organization and the extra-organizational environment rather than restrict its focus to operating personnel. Furthermore, the methodology should improve systemic thinking and critical reflection on the performance of the total system. This chapter deals with an empirical evaluation of the event analysis methodology Safety through Organizational Learning (SOL). The results show that shortcomings, such as the exclusive search for scapegoats, are overcome through SOL and that analysts are forced to take the total system into account while conducting an event analysis.

There are mainly two different understandings of the term "safety culture": Either the concept denotes mental, cognitive features that are not directly accessible (International Nuclear Safety Advisory Group [INSAG], 1991; Turner, 1978), or it comprises behavior patterns and directly observable artifacts characteristic of a given collective (ACSNI, 1993; Wilpert, 1991), as the definitions below show.

> Safety Culture is that assembly of characteristics and attitudes in organisations and individuals which establishes that, as an overriding priority, nuclear plant safety issues receive the attention warranted by their significance. (INSAG, 1991, p. 1)
>
> The safety culture of an organization is the product of individual and group values, attitudes, perceptions, competencies, and patterns of behavior that determine the commitment to, and the style and proficiency of, an organization's health and safety management. (ACSNI, 1993, p. 23)

> Safety culture is the shared consciousness and corresponding behavior of all system members that promote safety of the total system. (Wilpert, 1991, p. 6)

This last definition takes into account not only the corresponding behavior but also the reference to "the total system," which highlights the need to transcend the limitations of exclusively focusing on a single organization, such as a nuclear power plant, and to consider all actors that are able to contribute to safety, for example, consulting agencies, regulatory bodies, and public stakeholders (Fahlbruch & Wilpert, 1999). The approach to take the total system into account resulted from in-depth investigations into major disasters that showed that "outside" organizations contributed to the occurrence of these events. A comparison of different analytical methods for safety culture and climate (Büttner, Fahlbruch, & Wilpert, 1999) shows that different concepts of culture lead to different operationalizations. But often special attention is given to a feature of questioning attitudes and systemic thinking. How an organization treats experience and feedback data also seems to be an important feature of its safety culture. This circumstance leads to the significance of event analysis as a tool for organizational learning with regard to safety culture in the organization. This chapter deals with the relationship of event analysis methods and safety culture.

EVENT ANALYSIS

The theoretical concepts that event analysis methods are based on play a major role in determining the way an analysis is conducted and the limitations of analysis (Fahlbruch, 2000). Furthermore, the theoretical concept defines which contributing factors can be identified and therefore reported. Thus, the theoretical concept that an event analysis method is based on influences the quality of experience transfer and the organizational learning. Derived from the results of in-depth analyses, it is obvious that accident causation models focusing on the individual operator or on man-machine interaction lead to shortcomings. For an adequate modeling of reality, the focus should be broadened to include organizational and interorganizational factors (Fahlbruch, 2000; Fahlbruch & Wilpert, 1999).

It is not just the theoretical concepts but also the inherent goals of an event analysis that determine the comprehensiveness and depth of the analysis, that is, their "stop-rules" (Benner, 1981a, 1981b; Rasmussen, 1991). The goal of identification of liability or responsibility, which then leads to the end of the analysis once someone to blame has been found, is contradictory to the concept of safety culture. Goals that foster safety culture are the monitoring of the safety management system by identifying weak barriers through event analysis (Freitag & Hale, 1997), the maintaining of safety awareness by documenting and distributing accident rates as a result of event analyses

(Freitag & Hale, 1997), and the modeling of safety-relevant processes for organizational learning by identifying weaknesses through event analyses (Fahlbruch & Wilpert, 1997; Freitag & Hale, 1997; Rasmussen, 1991).

Shortcomings in event analyses arise not only from overly simplistic accident causation models or the implicit goal of identifying a scapegoat. The process of event analysis itself is jeopardized by the way humans make causal analyses. In a recent work I have reviewed epistemological findings as well as studies from the fields of cognition and attribution theory and identified major shortcomings in how humans search for causes of events (Fahlbruch, 2000). In brief, it can be stated that the process of identifying causes of events has three phases and is moderated by multiple variables. These phases are the generation of hypotheses, the testing of hypotheses, and the judging of causal relevance in relation to alternative explanations. The generation of hypotheses is influenced by psychological factors, such as a noticeable cause-and-effect relationship, the priority of the cause, and the difference to the background (Einhorn & Hogarth, 1986). According to Hilton and Slugoski (1986) and White (1995), the knowledge of the analysts plays a major role as well. Hypothesis-testing seems to depend on the given situation, variables used for are information about covariation, similarity of cause and effect, contiguity in time and space (Einhorn & Hogarth, 1986), and information about the necessity and sufficiency of the cause. Constraints or biases result from psychological factors as well as from overrating of confirming information; from adjustments to reference situations; from truncated search; from the presentation format of the method of analysis, for example, a fault tree, for it can be assumed that the more complete the figure provided seems, the more impact "out-of-sight, out-of-mind" factors will have; and from the tendency to attribute causes to persons rather than situations. The last phase is comparable to an adjustment process.

The process of identifying causes in event analyses therefore is jeopardized by the following shortcomings or biases:

1 Premature hypotheses can lead to restricted information and a restricted causal search.
2 Contributing factors that are remote in space and time are not identified, which leads to giving too much weight to directly contributing factors.
3 Monocausal thinking leads to the identification of only one contributing factor, even when there were multiple contributing factors.
4 Factors that contributed through their absence are skipped over, that is, something missing contributed to the event's occurrence, such as a missing "four-eye principle."
5 Contributing factors are identified based on past accidents.

6 Contributing factors that are not written down in the presentation of the method (e.g., a given checklist or fault tree) are not taken into account ("out of sight, out of mind").
7 Too much emphasis is placed on human contributions.

An event analysis method should support the analyst in overcoming the above shortcomings and thereby lead to results that are relevant in promoting safety culture.

SAFETY THROUGH ORGANIZATIONAL LEARNING

The Research Center Systems Safety at the Berlin University of Technology has developed a specific event analysis method, the so-called Safety through Organizational Learning (SOL) method, to overcome the shortcomings listed above. In the beginning the development concentrated on the nuclear industry (Becker et al., 1995; Wilpert et al., 1997); since then, versions for the chemical industry (Wilpert, Miller, Geymüller, Uhlemann, & Ninov, 1998) and civil aviation (Culemann, 1999) have also been developed. Researchers at the center recently worked on a computer-supported version (Wilpert, Maimer, & Loroff, in press).

As stated above, an event analysis method based on an adequate accident causation model can be judged to be a central contribution to organizational learning and safety culture. The theoretical basis of SOL is the socio-technical event causation model, which postulates that in high-hazard industries events occur because of the interaction of directly and indirectly contributing factors from the subsystems of the "individual," the "team," the "organization," the "extra-organizational environment," and "technology." Furthermore, events have multiple causes and can be seen as a sequence of different subevents. Based on this theoretical model, potential contributing factors were generated and complemented by empirically obtained factors. This collection was structured and categorized according to the five subsystems, resulting in a set of 20 potential human-factor—categories, including organizational and extra-organizational categories, and one technical category:

- presentation of information
- information-processing
- communication
- work conditions
- personal performance
- operation-scheduling
- violations
- responsibility

- supervision and control
- group influence
- technical components
- rules and procedures
- qualifications
- training and selection criteria
- organization/management
- feedback from experience
- safety principles
- quality control/quality management
- maintenance
- regulatory bodies
- environmental influence

As discussed above, an event analysis is influenced not only by the theoretical model applied and the implicit goal; the quality of the analysis also depends on the conceptualization of the analysis process itself (Fahlbruch, Miller, & Wilpert, 1998). In SOL, this conceptualization is one of a backward-oriented reconstruction or problem-solving process (Fahlbruch et al., 1998; Fahlbruch & Wilpert, 1997) with support for the analysts. Hence, an analysis using SOL is conducted in two separate steps: the description of the event situation and the identification of contributing factors. This clear separation of information-gathering and interpretation of the data was chosen in order to minimize the limitations brought on by premature hypotheses.

The event is then broken down into single event sequences, so-called event building blocks, in order to clarify what happened, but not why it happened. The information gathered is categorized into the event building blocks according to type of actor (human and machine actors), action, time, location, and the possibility of adding analysts' comments. The event building blocks are then ordered into a matrix in order to recompose the event. This recomposition is the starting base for the subsequent identification of a contributing factor; an identification aid supports analysts in this task. A separate analysis is conducted for each event building block in order to prevent monocausal thinking, truncated search, and limitations due to premature hypothesis. Identified contributing factors are added to the matrix; in this way, the picture of the accident, that is, the reconstruction, is completed in succession. The identification aid consists of the human-factor categories in order to ensure depth of investigation and support the analysts in generating a hypothesis or building long causal chains to bridge time gaps between causes and the event. The human-factor categories are grouped into directly or indirectly contributing factors, but some, such as work conditions, are grouped into both. Marks of reference from directly contributing factors to indirectly contributing factors help the analysts identify causes that are remote in time and space. These marks of reference also serve to overcome a concentration on human contributions by guiding the analysis from human performance to factors from the other subsystems. Furthermore, they act as a barrier against monocausal thinking. In sum, SOL overcomes the problems of limited event analysis in the following ways:

1 Prevention against premature hypotheses leading to a restricted information and causal search is promoted through the separation of the information search from the identification of contributing factors and through the rule that factors for each event building block must be identified separately.
2 In order to support the identification of factors that are remote in time and space, there are marks of reference from directly to indirectly contributing factors as well as examples of how the gap could be bridged.
3 The procedure prescribing that a separate analysis as well as the above-mentioned marks of reference should be carried out for each event building block helps prevent monocausal thinking.
4 Questions and examples in the identification aid help identify factors that contributed to the event through their absence.
5 Rules for information and causal search (for each event building block separately) prevent the identification of contributing factors based on past accidents.
6 In SOL, the impression of completeness is avoided by making the incompleteness of examples explicit and by leaving out a detailed presentation of very specific subcategories. Thus, the impression of incompleteness should support the analysts in identifying “out-of-sight” factors.
7 Marks of reference from human-related contributing factors to the other subsystems serve to prevent against a concentration on individual human contributions, such as operators’ performance.
8 SOL’s scope of investigation covers organizational and extra-organizational factors.

Furthermore, SOL is developed for group analysis, that is, for analysis by a team that also includes staff directly involved in the event, which should also help minimize biases and constraints. Whether the theoretical evaluation will be confirmed by the empirical data is tested in experimental designs and field case-studies. The following section gives selected results of this testing for validity.

SELECTED RESULTS OF THE EXPERIMENTAL EVALUATION OF SOL

In order to solve the problem of causes of events only being identified in hindsight, so that nobody knows the "true" causes, a part of the experimental evaluation was carried out through "constructed" cases, for which the cause was determined a priori. Thus, a measurement of the "true" causes was obtained, and the empirically identified causes could be compared with the "true" ones. According to the principles of safety culture, the results of overcoming restrictions due to premature hypotheses, monocausal thinking, and a concentration on the human contribution seem to be particularly relevant (for all of the results, see Fahlbruch, 2000).

Four different case studies (one accident at home, two occupational accidents, and a collision of two ships) were constructed by students for the experimental analysis using SOL. Employing SOL methodology, 120 students conducted 60 event analyses of the four cases. They received a short description of the accident and had the opportunity to ask questions in order to collect more information and complete the situational description and the identification of contributing factors.

With regard to a restriction of causal search due to premature hypotheses, only a subset of 22 analyses served as the database. The comparison between correctly stated hypotheses after the description of the event and correctly identified contributing factors was chosen as the indicator for overcoming restrictions due to premature hypotheses. If the restriction was overcome, the number of correctly identified contributing factors should be greater than the number of premature hypotheses. The overall results showed that the average number of correctly stated hypotheses was 1.86 ($s=0.97$, $n=22$), whereas the average number of correctly identified contributing factors was 8.27 ($s=2.9$, $n=22$). Figure x.1 shows the results of the comparison. The difference found was highly significant: $\chi^2=89.16$ ($\chi^2_{1.99\%}=6.635$; $p<.01$); significantly more correctly identified factors were found through using SOL than premature hypotheses were generated.

Indicators also had to be chosen for the question of whether SOL overcomes monocausal thinking. Someone who thinks monocausally should not identify more than one factor. The results of 60 analyses were therefore tested in terms of the number of identified human-factor categories. This measurement is rather conservative, because one single human-factor category could contribute directly and indirectly. Overall, 98.3% of the subjects identified more than two human-factor categories. Figure 14.2 shows the distribution of identified human-factor categories in relation to the number of subjects.

Whether SOL adequately protects against concentration on the individual human contribution in the analysis was tested by comparing the number of identified contributing factors that were related to the individual human contribution with those factors that were unrelated. Factors judged to be

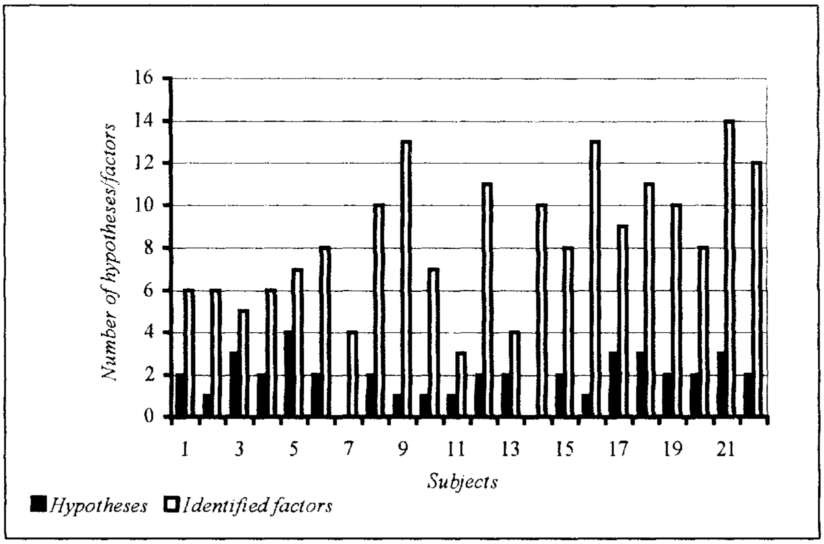

Figure 14.1 Comparison of the number of correctly stated hypotheses with the number of correctly identified factors

related to individual human contributions were communication, personal performance, violations, and qualifications. All other factors were considered to be nonindividual human contributions. Once again, the test considered only correctly identified contributing factors. Altogether, 577 contributing factors were identified, of which 244 factors were judged to be individual human contributions and 333 factors to be nonindividual human contributions. The difference between them was highly significant: . $\chi^2=13.72$ ($\chi^2_{1.99\%}=6.635$; $p<.01$) The number of factors that were not judged to be individual human contributions was significantly higher. Thus, it may be concluded that SOL helps prevent concentration on the individual human contribution.

SOL has also been evaluated by scientists and practitioners around the world. They either assessed the content validity and usability of SOL or conducted an analysis using SOL in order to evaluate its performance. The results showed that SOL was judged to be a comprehensive methodology that is relatively simple to use. Case studies of nuclear power plant events showed that SOL leads at least to the same or even better results than other methods in use. SOL was again judged to be a methodology that is easy to use and that supports practitioners in nuclear power plants, enhancing systemic thinking and a questioning attitude. These results from the field have the status of single case studies, but a more systematic benchmarking study is planned for the future.

Taken together, these results show that SOL seems to be a valid event analysis method that identifies contributing factors from a wide range of possible system levels—individual, organizational, and extra-organizational.

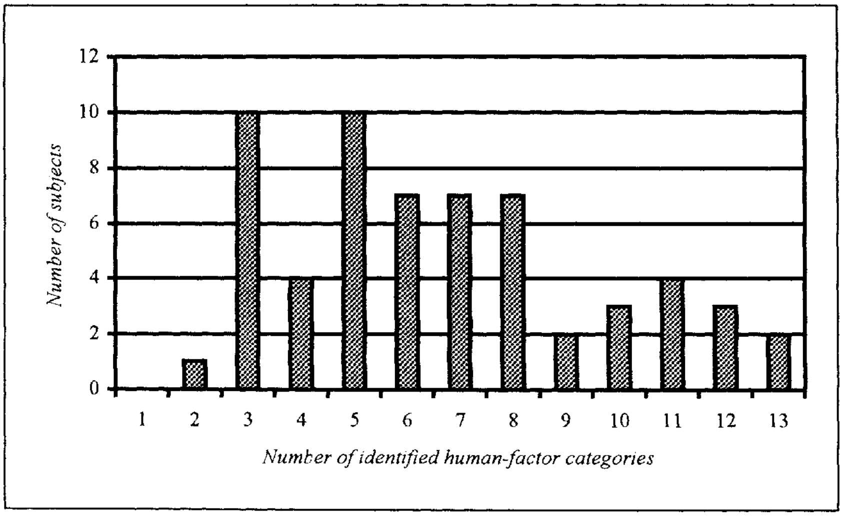

Figure 14.2 Number of subjects grouped with the number of identified human-factor categories

Conducting an event analysis with SOL enforces systemic thinking because the whole network of contributing domains and their interactions are taken into account. The results also include organizational weaknesses, which offer opportunities for improvement and for learning from experience. The analysis of events by a team that includes staff involved in the event fosters an attitude of critical reflection on the total system performance. Both characteristics, systemic thinking and critical reflection, are necessary parts of a good safety culture. Therefore, SOL may be judged to support the safety culture of an organization and its organizational learning.

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PART FOUR

Managing personnel and work place issues in nuclear power operations

Introduction

Part Four addresses the role of people in the nuclear industry and provides a set of concrete studies and interventions which focus on human resource management, operator action, and human error.

A research study of the role of implicit safety-related norms in their impact on safety behavior is reported on by Ignatov. The study took place in an East European nuclear power plant, uses an innovative scenario methodology, and shows that, contrary to expectations, it is less safety-related attitudes that influence behavior than safety-related, implicit, often unconscious, norms. This finding has important implications for leadership and training in nuclear power plants.

The three chapters by Yoshizawa, by Sakuda, and by Tsukada and Kotani all focus on the problem of how to reduce human error in the nuclear industry. They report on different Japanese approaches to the use of near misses as consciousness-raising units, to systematic interventions through basic and advanced training measures (Yoshizawa, Sakuda), to the development of a model-based human error prevention approach, and to consensus-building strategies through (Intranet) knowledge-sharing and the anonymous reporting of incidents (Tsukada & Kotani). Of particular value for the reader may also be the information provided in the chapters about why certain measures failed and how a redress was found.

The concluding chapter by Fukui, Kosaka, and Kotani describes a comprehensive approach to designing a coherent visual communication system to help nuclear power plant staff orient themselves and understand complex work environments.

CHAPTER FIFTEEN
Subjective Norms and Procedural Noncompliance in Nuclear Power Plants

MARIN IGNATOV

The explicit normative bases of all activities in nuclear power plants are the written procedures and rules. The explicit structuring of work tasks is supported through the omnipresent procedure manuals as well as written and oral orders and regulations. A good deal of evidence shows, however, that even in such extremely regulated environments the explicit rules are not always followed. This chapter reports on a study, carried out in an Eastern European nuclear power plant, that examined the interrelationship between written procedures and subjective norms. The first step of this study encompassed discussions and open-ended interviews with control room operators and unit managers. The aim of this initial effort was to produce real-life scenarios with subjective norms. The consequent iterative research process included collection and analysis of data, the planning of procedures, and facilitation of the exchange of information in group feedback sessions. Results show support for subjective norms as predictors of safe performance at the individual level.

Operators' behavior within a nuclear power plant derives from institutionalized procedures. The structuring of work tasks is supported through procedure manuals as well as other regulations. The correspondent behavior does not follow the written regulations in an automated way but rather is modified through psychological processes of "redefinition." An important research question is how safety-related subjective norms "redefine" written safety-related procedures and rules. Hackman (1970) stated that the redefinition process depends on three cognitive systems: (a) adequate or inadequate perception of the task and the circumstances, (b) the individual's readiness for specific action, and (c) the individual's experiences with the same or similar tasks.

One may assume that safety-related subjective norms influence all three regulatory systems. They modify the perception of a given task, influence individual readiness for action, and shape the individual's experiences in order to bring them into accord with group expectations. Both written procedures and safety-related subjective norms give rise to patterns of behavior that in some cases might be contradictory in nature. Sometimes, to follow a tacit safety-related norm might lead to an improved or more efficient control style than would strict adherence to written procedures, but it might also diminish efficiency and even lead to incidents. Procedural compliance in nuclear power plants may have grave implications for operational safety. It is therefore still a matter of concern for the management of nuclear utilities.

RESEARCH MODEL

The assumption that subjective norms and attitudes may regulate the individual's intentions and behavior is implied in the theory of planned behavior (Ajzen, 1987). This theory takes into consideration the influence of personal evaluations, perceived social pressure, and perceived control in predicting the intention to perform a given behavior. The theory of planned behavior is an extension of the theory of reasoned action (Ajzen & Fishbein, 1972), which initially included personal evaluations (attitudes) and perceived social pressure (subjective norms) as the most powerful antecedents to the intention to perform a behavior.

The theory of planned behavior adds the construct of perceived behavioral control (Ajzen, 1987). Ajzen (1987, 1991) argued that in order to act a person must have control, that is, relevant personal resources and appropriate environmental opportunities. Ajzen pointed out that perceived behavioral control, which is a measure of the respondent's perception of how easy it is for him or her to perform a given action if he or she so wishes, is often closely related to the person's actual control. Thus, perceived behavioral control provides an index of actual control and may have a direct effect on behavior (as well as an indirect link by means of intention). When the behavior poses little problem of control, intentions alone are sufficient to predict it. But perceived behavioral control becomes a significant predictor when there is less control of behavior. Support for the direct influence of perceived behavioral control on intention has been found in each of the 16 studies reviewed by Ajzen (1991).

According to the theory of planned behavior, personal behaviors are determined by behavioral intentions. Behavioral intentions are a function of attitudes, subjective norms, and perceived behavioral control. In the theory of planned behavior the attitude toward an action, measured by the sum of the products of beliefs, reflects the general feeling for or against the action based on its expected outcomes. This feature makes the theory an expectancy value model. The subjective norm is conceived of as a perceived social pressure or influence from persons and groups important to the subject. Antecedents to attitudes and norms are outcome beliefs and normative beliefs. Antecedents to perceived behavioral control are beliefs about the ease with which one can execute the behavior and beliefs about resources and obstacles related to the behavior. The perceived behavioral control can be operationalized as the sum of the products of factors affecting control over the behavior and the relative strength of these factors. The measure of perceived behavioral control may be underwritten by specific beliefs, called control beliefs. Control beliefs can be measured either directly or as the product of two measures: the power of a factor to assist the action and a control access measure.

Ajzen's position is that the measurement of attitude, subjective norm, and perceived behavioral control should be sufficient for the prediction of intention. Attitudes, subjective norms, and perceived behavioral control are considered to be the most powerful predictors of intention; therefore, the model does not include any background variables, such as age or education, which describe the population. It is assumed that individual qualities, such as educational attainment or ethnic origin, indirectly affect attitudes by shaping beliefs and evaluations (Madden, Ellen, & Ajzen, 1992).

The attitude toward an action or object is the sum of the products of beliefs about the behavioral outcome (expectancy) and the evaluation of this outcome (value). The determinants of the attitude to the behavior are the outcome beliefs with two components, an expectancy component and a value component. The expectancy component is measured as the likelihood that the outcome will occur if the action is taken, and the value component is measured as an evaluation of the outcome when it does occur. The outcome belief is given by the product of these components, and the sum of the outcome beliefs determines the attitude. A distinctive aspect of this approach is that the outcomes affecting the attitude are restricted to those that are salient, that is, to those outcomes that are easily brought to mind by investigation participants. Nonsalient beliefs are unlikely to affect behavior.

The subjective norm is the sum of the products of normative beliefs about the expectations of others (expectancy) and the motivation to comply with these expectations (value). It is based on salient normative beliefs about whether particular referents think the respondent should or should not do the action in question. Like expected outcomes, these influences of referents are covered by two measures: the likelihood that the referent holds the normative belief and the motivation to comply with the views of the referent. These subjective norms have an implicit, tacit character.

The research model of the present study proposes three predictors in addition to attitudes and referent-related subjective norms: situation-related subjective norms and the two types of internalized norms (compliant and noncompliant norms).

The *situation-related subjective norm* may not be identical with norms, which are influenced by reference persons or a reference group. There are cases in which people with no or very little reference value influence a situation simply by witnessing it, so that they become normatively important for the actor. The experience of trespassing a street-crossing against red lights appears to be more stressful or difficult when others are present and not crossing on red. The situation-related subjective norm, which reflects such situation-related social pressure, is based on salient situation-related normative beliefs about whether particular witnesses or participants in a situation think the respondent should or should not do the action in question. Like attitudes and referent-related norms, these situation-related influences are covered by two measures: the likelihood that the witness holds the normative belief and the motivation to comply with the views of the witness.

Of a very different nature are the *internalized compliant or noncompliant norms*. The mental salience of past experience is another very important factor, which is not taken into account within the theory of planned behavior. If individuals are affected by the perceived standards of important others, they are also likely controlled by institutional norms, which have been internalized and have become something like an ethical or moral imperative. These internalized compliant norms may regulate intention and behavior, without any presence of social pressure (i.e., sanctions). This circumstance makes the internalized compliant norm, experienced as an ethical or moral imperative, an important predictor of intention. On the other hand, past experience of noncompliance may develop a normative character and become a habit of noncompliance.

APPLICATION OF THE RESEARCH MODEL TO AN INVESTIGATION OF THE PROCEDURAL COMPLIANCE IN AN EASTERN EUROPEAN NUCLEAR POWER PLANT

The overall purpose of the investigation was to develop and test a method for analyzing the mechanisms of procedural compliance, using the theory of planned behavior as a guide. The research model is operationalized in seven steps, which are summarized as follows:

Step 1 selecting the behavior of interest and defining it in terms of its action, target, context, and time elements;
Step 2 defining specific classes of the behavior of interest with the corresponding written procedures, attitudes, subjective norms, and behavioral intentions;
Step 3 selecting the salient classes of behavior and developing scenarios;
Step 4 eliciting the salient outcome, normative, and perceived control beliefs about the target behavior;
Step 5 developing questionnaire items from the salient outcome, normative, and perceived control beliefs;
Step 6 applying the questionnaire to a representative sample; and

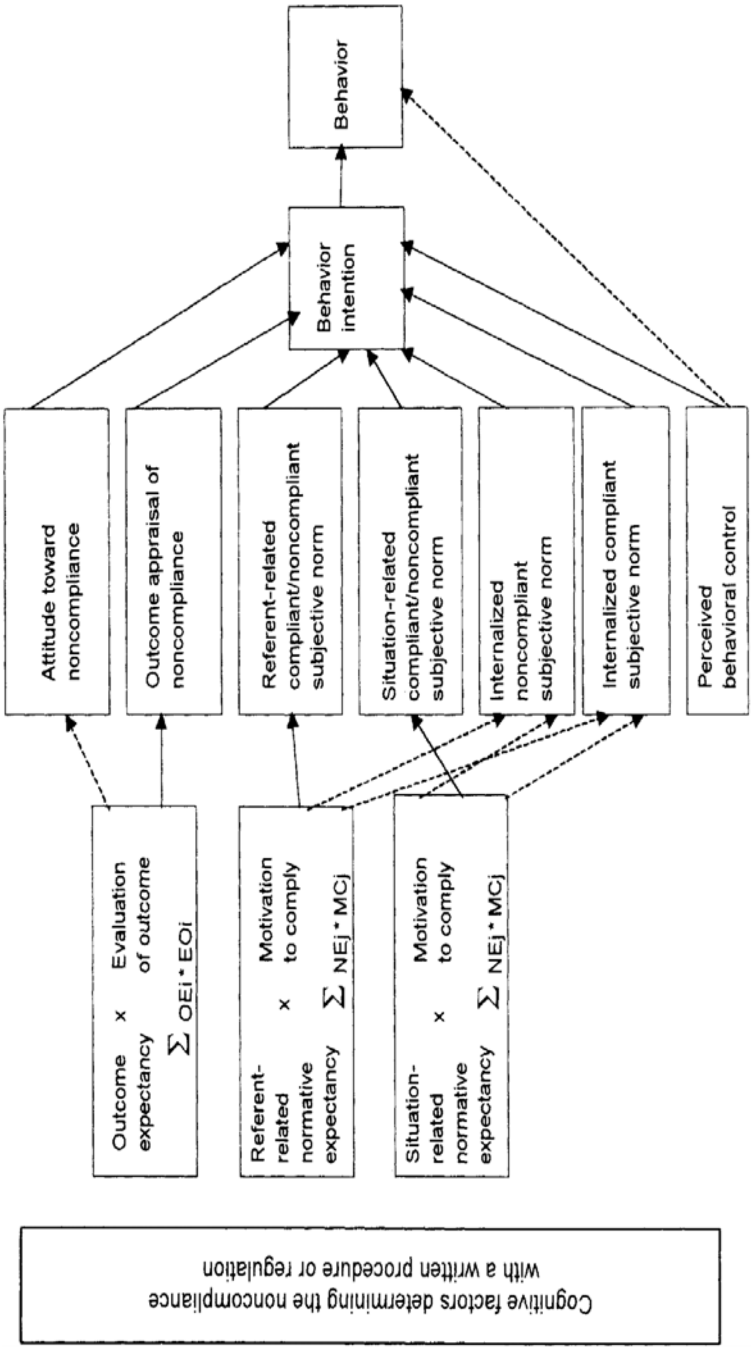

Figure 15.1 A research model for analyzing tacit safety-related subjective norms, based on the theory of planned behavior.

Step 7 evaluating and interpreting the questionnaire results.

The instrument development was conducted according to the work of Parker, Manstead, Stradling, and Reason (1992a, 1992b), Parker, Manstead, and Stradling (1995), Parker, Stradling, and Manstead (1996), and the earlier guidelines of Ajzen (1991).

Step 1:
Selecting the behavior of interest and defining it in terms of its action, target, context, and time elements

During an initial feasibility study in an Eastern European nuclear power plant, a review of safety documents and procedures was carried out. Psychological and managerial knowledge was transmitted in several meetings, discussions, and seminars in order to increase the acceptance of human factors research methods and approaches among the nuclear power plant's operators and managers. Specific team-building and group-discussion techniques were applied. As a result of these group discussions, a behavioral target was specified in accordance with the executives of the plant. The target behavior was the procedural compliance performance of operational and maintenance personnel. This behavioral target is an indicator of safety culture and appears in the Assessment of Safety Culture in Organizations Teams (ASCOT) Guidelines (1996).

Step 2:
Defining specific classes of the behavior of interest with the corresponding written procedures, attitudes, social norms, and behavioral intentions

In order to maintain consistency with the target, the behavioral intention to deviate from a specified procedure or regulation was specified. This intention was measured on a 7-point Likert-type scale ranging from "extremely likely" to "extremely unlikely."

Step 3:
Selecting the salient classes of behavior and developing scenarios

The instrument development began with the formulation of hypothetical scenarios, which were related to the target behavior of procedural compliance. Sixteen senior members of the nuclear power plant's managerial personnel acted as participants in a group discussion. They were asked to make judgments about 15 standardized, hypothetical scenarios. The scenarios depicted different aspects of safety-related subjective norms. Each scenario contained the opportunity for a procedural noncompliance. The person who committed the procedural noncompliance understood the deliberate nature of his or her behavior. The procedural noncompliance was related with the system safety of the unit and was placed in the border zone between “accepted” and “nonaccepted” behavior. The scenarios were developed in such a way that the actor might or might not notice the presence of other persons.

The aim was to have the group discussion of the scenarios evoke mental pictures with sufficient detail to give investigation participants a clear image of the scene. The scenarios were evaluated by 16 senior members of the managerial personnel, according to their assumed importance for procedural compliance. Each of the participants in the discussion received the task of allocating three color marks (one red mark for first priority: three points; one yellow mark for second priority: two points; and one blue mark for third priority: one point). Table 15.1 shows the achieved rankings of the different scenarios.

As a result of the scenario selection procedure, four scenarios were selected for the operating personnel and four scenarios for the maintenance personnel. In addition, both samples were confronted with four nonspecific safety-related scenarios (from the area of driving in traffic). The present chapter considers only the nuclear-specific scenarios for the operating personnel, which were:

Scenario 1: Failure to pass on information to superiors about colleagues, superiors, or subordinates’ noncompliance with procedures.

Scenario 2: Contradictory behavior of a superior, who talks about safety as a first priority but makes depreciative remarks about existing procedures.

Scenario 3: Individual rating of the importance of procedures: some procedures are considered to be important, so it is assumed that for them absolute compliance is expected; others, on the contrary, are considered to be not so important, so it is assumed that for them absolute compliance is not expected.

Scenario 4: An electronic display is trusted less than the operator’s own feeling or experience.

Step 4: Eliciting the salient outcome, normative, and perceived control beliefs about the target behavior

This step encompassed a group discussion with 13 senior members of the nuclear power plant’s managerial staff (a different group of discussants, than the first one with 16 members). They were asked to make judgments about

Table 15.1 Ranking of the Initial 15 Scenarios for the Operating Personnel

Scenario type	Number of allocated color marks (one red mark is three points, one yellow mark is two points, one blue mark is one point)			Ranking (points)
	Red color marks	Yellow color marks	Blue color marks	
Failure to pass on information to superiors about colleagues, superiors, or subordinates' deviations from procedures	4	6		24
Failure to pass on information to superiors about one's own deviations from procedures		1		2
An electronic display is trusted less than the operator's own experience or feeling	3	1	2	13
Compromise with observance of the working time schedule (within a shift)		1		2
Compromise with observance of the working time schedule and the substitution regulations (between shifts)		2		4
Compromise with alcohol consumption on the job	1			3
Compromise with smoking regulations on the job			1	1
Compromise with spare parts specifications				0
Compromise with repair procedure documents			1	1

Scenario type	Number of allocated color marks (one red mark is three points, one yellow mark is two points, one blue mark is one point)			Ranking (points)
	Red color marks	Yellow color marks	Blue color marks	
Different ranges of tolerance for complying with written norms in procedures or manuals (younger vs. Older operators)		1	1	3
Contradictory behavior of a superior, who talks about safety as a first priority but ignores specific deviations of his or her subordinates from procedures or regulations			1	1
Contradictory behavior of a superior, who talks about safety as a first priority but makes depreciative remarks about existing procedures	6	2	1	23
Contradictory behavior of a superior, who talks about safety as a first priority but is himself a bad example in procedural compliance			2	2
Restriction of the scope of application of procedures in ambiguous situations		2		4
Individual rating of the importance of procedures: some procedures are considered to be important, so it is assumed that for them absolute compliance is expected; others, on the contrary, are considered to be not so important, so it is assumed that for them absolute compliance is not expected.	2		7	13
Total	16	16	16	96

different outcome beliefs and different referents. The 13 group discussants were asked to imagine one of the four nuclear-specific scenarios for the operational personnel and then were asked if they could think of any reasons why they might act in the way indicated or why they might refrain from doing so. The discussants were encouraged to list both the advantages and disadvantages associated with procedural compliance and to discuss any other factors that they considered in relation to this topic. In this way, a list of the four most commonly expressed positive and negative outcome beliefs about each of the scenarios was compiled.

Selected positive expected outcomes of a procedural noncompliance were: (a) to save oneself additional work, trouble, or effort; (b) to achieve material benefit or time gains; (c) to achieve respect by showing high abilities, skills, and knowledge; and (d) to achieve sympathy, a higher informal position, or influence. Selected negative expected outcomes of a procedural noncompliance were: (a) to receive sanctions or penalties; (b) to endanger one’s own safety, the safety of other persons, or the environment; (c) to lose respect by showing low abilities, skills, and knowledge; and (d) to lose sympathy, an informal position, or influence.

In order to obtain normative beliefs, the 13 senior members of the managerial staff were asked to identify individuals or groups who would approve and/or disapprove of their eventual procedural noncompliance or who might have any other influence on their behavior. This procedure enabled the identification of salient normative beliefs and referents with respect to each of the four scenarios. In order to obtain referents from different types, a stratified procedure was used. The two most frequently mentioned referents were chosen for each of the following four different referent types. Based on this rating procedure, the following eight referents or reference groups were identified:

Reference Type 1: superiors in the nuclear power plant

- the general manager of the nuclear power plant
- the next superior line manager

Reference Type 2: friends and colleagues

- the colleague for whom the respondent has the highest esteem
- the best friend of the respondent

Reference Type 3: important groups of personnel in the nuclear power plant, such as the engineers and maintenance personnel

- the majority of the operational personnel in the nuclear power plant
- the majority of the maintenance personnel in the nuclear power plant

Reference Type 4: general national stereotypes, for example, the “typical German” or “typical Czech”

- the “typical” representative, of one’s own sex and age, of the corresponding Eastern European nation
- the “typical” Western European, of one’s own sex and age

Step 5:
Developing questionnaire items from the salient outcome, normative, and perceived control beliefs

This step comprised the instrument construction. The scenarios, the salient outcome beliefs, and salient referents generated in Steps 3 and 4 were combined in a questionnaire, which consisted of several types of items. The behavioral intention of noncompliance was measured with three items: (a) the declared intention to commit the procedural noncompliance, (b) the decision to commit the procedural noncompliance, and (c) the evaluation of the likelihood to commit the procedural noncompliance.

Two items were developed for each outcome belief: a value item and a likelihood item. In a similar way, two items were developed for each normative belief: a likelihood item and a motivation-to-comply item. Altogether there were eight pairs of items for referents/reference groups and one pair for situation witnesses. The internalized compliant and noncompliant subjective norms were measured directly with one item per norm. The perceived behavioral control was measured with three items, which assessed the ease with which investigation participants feel they can avoid committing the procedural noncompliance in question.

An index of attitudes for each of the scenarios was calculated by summing the products of each outcome belief and its corresponding outcome evaluation. An index of referent-related noncompliant norms was obtained by summing the products of each normative belief and the corresponding motivation to comply. The situation-related noncompliant norm was a product of the corresponding normative belief and the corresponding motivation to comply.

RESULTS

The questionnaire was applied to 315 investigation participants, but for this chapter only 110 cases of tested operational personnel were considered. The group of operational personnel was divided into two subgroups: shift operational personnel (76 participants) and daytime operational personnel (34 participants). The participants were stratified by five age groups, two educational levels, and sex.

Table 15.2 Age Distribution in the Sample (Chi-Square-Test, p<0.007)

	Shift operational personnel	Daytime operational personnel	Total	Shift operational personnel (%)	Daytime operational personnel (%)	Total (%)
Under 30	14	5	19	18.4	14.7	17.3
31–35	19	6	25	25.0	17.6	22.7
36–40	24	4	28	31.6	11.8	25.5
40–45	13	8	21	17.1	23.5	19.1
Over 45	6	11	17	7.9	32.4	15.5
Total	76	34	110	100.0	100.0	100.0

Table 15.3 Sex Distribution in the Sample (Chi-Square-Test, p<0.043)

	Shift operational personnel	Daytime operational personnel	Total	Shift operational personnel (%)	Daytime operational personnel (%)	Total (%)
Males	69	26	95	90.8	76.5	86.4
Females	7	8	15	9.2	23.5	13.6
Total	19	6	110	100.0	100.0	100.0

Scenario 1: Failure to pass on information to superiors about colleagues, superiors, or subordinates' noncompliance with procedures.

Scenario 2: Contradictory behavior of a superior, who talks about safety as a first priority but makes depreciative remarks about existing procedures.

The subgroups (shift operational personnel and daytime operational personnel) differed significantly in their distribution of age, sex, and educational level. This finding is in accordance with expectations. Very often, the career development of shift personnel leads to their transfer to daytime positions. The daytime personnel included more senior managerial positions, hence the differences in educational level and age. The female operational personnel was clearly in a minority position, although an even smaller percentage of women was initially expected.

Table 15.4 Distribution of the Educational Level in the Sample (Chi-Square-Test, p<0.004)

	Shift operational personnel	Daytime operational personnel	Total	Shift operational personnel (%)	Daytime operational personnel (%)	Total (%)
University or technical college	31	24	55	40.8	70.6	50.0
Technical high school	45	10	55	59.2	29.4	50.0
Total	76	34	110	100.0	100.0	100.0

Table 15.5 Multivariate Stepwise Regression Analysis for Scenario 1 (Model 1)

Model		Nonstandardized coefficients		Standardized coefficients	T	Significance	Correlation		
		B	Standard error	Beta			Zero order	Partial	
1	Constant	.805	.090		8.946	.000			
	Situation-related normative belief x Motivation to comply (Sc5)	.104	.012	.643	8.486	.000	.643	.643	.643

Multiple regression analyses were used to examine the contributions of attitudes, subjective norms, and perceived behavioral control to the explanation of behavioral intention. The results of the multiple regression analyses are presented in Tables 15.5–15.8.

Scenario 3: Individual rating of the importance of procedures: some procedures are considered to be important, so it is assumed that for them

Table 15.6 Multivariate Stepwise Regression Analysis for Scenario 2 (Model 1)

Model		Nonstandardized coefficients		Standardized coefficients	T	Significance	Correlation		
		B	Standard error	Beta			Zero order	Partial	
1	Constant	1.385	.275		5.037	.000			
	Internalized noncompliant subjective norm (Sc6)	.713	.061	.757	11.746	.000	.757	.757	.757

absolute compliance is expected; others, on the contrary, are considered to be not so important, so it is assumed that for them absolute compliance is not expected.

DISCUSSION

The results of the multiple regression analyses for the nuclear-specific scenarios show that, in general, the proposed theoretical model may serve as a basis for explanations and further research. A major strength of the measurement approach is the structuring of the instrument development process in several steps using both qualitative and quantitative aspects.

Scenarios 1 and 3 appear to elicit context-related behaviors. In Scenario 1 (failure to pass on information to superiors about colleagues, superiors, or subordinates' noncompliance with procedures), the situation-related noncompliant subjective norm is the most important predictive factor. In Scenario 3 (individual rating of the importance of procedures), the referent-related noncompliant subjective norm is the main predictive factor.

Rather different were the results for Scenario 2 (contradictory behavior of a superior, who talks about safety as a first priority but makes depreciative remarks about existing procedures) and Scenario 4 (an electronic display is trusted less than the operator's own feeling or experience). For these

Table 15.7 Multivariate Stepwise Regression Analysis for Scenario 3 (Model 1)

Model		Nonstandardized coefficients		Standardized coefficients	T	Significance	Correlation		
		B	Standard error	Beta			Zero order	Partial	
1	Constant	.466	.187		2.485	.015			
	Referent-related normative belief x Motivation to comply (Sc7)	.178	.019	.679	9.394	.000	.679	.679	.679

scenarios, the underlying internalized noncompliant norms were a major factor in the prediction.

There is no scenario for which the attitudinal aspects are the most important predictive factor. This finding supports the assumption that safety-related behaviors in a nuclear power plant are highly norm-specific. In contrast, in several studies by Trafimow (1994, 1996), the prediction of intentions is analyzed as largely due to the attitude component. This finding is coupled with the lack of prediction from subjective norms and perceived behavioral control. Trafimow suggested implications for interventions designed to change attitudes. One way attitudes can be changed is by educating people about the negative consequences of their actions or by challenging their positive expectancies. Trafimow's research points out the importance of attitudes and indicates the relative unimportance of subjective norms in predicting intentions in college undergraduate samples.

In the specific setting of the nuclear power plant, however, such a strategy aimed at changing attitudes (and outcome beliefs) does not appear to be effective. The highly structured social environment of a nuclear power plant does not allow for big differences in basic attitudes. A safety-negligent

Table 15.8 Multivariate Stepwise Regression Analysis for Scenario 4 (Model 1)

Model		Nonstandardized coefficients		Standardized coefficients	T	Significance	Correlation		
		B	Standard error	Beta			Zero order	Partial	
1	Constant	.407	.112		3.636	.000			
	Internalized noncompliant subjective norm (Sc8)	.737	.072	.708	10.231	.000	.708	.708	.708

person will not be working there for long, just because this type of behavior is not accepted. So the more subtle differences in group norms become more important. In two scenarios, the normative beliefs are a predictive factor, whereas in the other two scenarios internalized habits and "traditions" of noncompliance appear to be important.

An interpretation of the present data should also take into consideration the specific cross-cultural aspects of Eastern Europe. There are differences between individualistic and collectivistic cultures (Triandis, 1994, 1995), and one such difference might be the degree of emphasis placed on norms by these two types of societies. Consequently, it appears feasible that there are more norm-regulated behaviors in collectivistic cultures than in individualistic ones. If so, then manipulations of subjective norms generally should be more effective in collectivistic cultures. The utilization of behavior-specific referents appears to be an underestimated opportunity to increase the effectiveness of interventions directed at changing norm-regulated behaviors.

In addition, there are instrument-related issues to be discussed. The findings of this study have potentially important implications for the theory of planned behavior. It is possible that the findings about the greater predictive value of attitudes, found elsewhere, may at least in part be due to a methodological artifact. As Trafimow and Fishbein (1994a, 1994b, 1995) point out, the recommended measuring of subjective norms by asking participants to indicate the extent to which their “most important others” think they should or should not perform the behavior in question may lead respondents to consider general but not behavior-specific referents. In the case of the present study, the use of specific referents together with the situation witnesses allows this underestimation of the relative contribution of normative considerations as determinants of behavioral intentions to be overcome.

In conclusion, the results allow a differentiated assessment of the predictive strength of several factors on procedural compliance in a nuclear power plant. This study shows that it is possible to assess the predictive power of safety-related norms from empirical data through an iterative research process of collecting and analyzing data, planning procedures, and facilitating the confidential exchange of information between respondents and researchers. There is consistent evidence to show that even in such extremely regulated environments, the institutional or official procedures and instructions are not always followed. However, in such very sensitive settings as nuclear installations, the effect of social desirability cannot be underestimated. In the present study, the strategies to minimize social desirability included an explanation of the aggregate nature of data analysis, assurances of confidentiality, and a clear separation of the data collectors from the psychological laboratory of the nuclear power plant.

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CHAPTER SIXTEEN
Activities for On-site Application Performed in the Human Factors Group

YURIKO YOSHIZAWA

The Human Factors Group of Tokyo Electric Power Company's (TEPCO) Nuclear Power Research & Development Center joined with three TEPCO Nuclear Power Stations in order to support safety activities that prevent human error. The Human Factors Group developed a method to analyze incidents and Hiyari-Hatto (near-miss) cases to support these safety activities. Moreover, the Human Factors Group investigated High Reliability Organizations, that is, organizations that maintain safety performance at a high level, in order to acquire some tips about their essential characteristics and apply these tips to the promotion of safety activities. Finally, the Human Factors Group is currently developing a Hiyari-Hatto database system so that Hiyari-Hatto cases can be shared via an Intranet.

The Tokyo Electric Power Company (TEPCO) Human Factors Group was established in July 1991. In the beginning its focus was on research to extract problems concerning human factors, and there were not many activities in direct support of the work of nuclear power plant operations and maintenance. Subsequently, we at the Human Factors Group have been engaged in practical research aimed at on-site application. Topics include team performance and field operation and are based on lessons learned from actual incidents in our nuclear power stations. We currently are developing educational programs on human factors, based on what has been learned from analyzing *Hiyari-Hatto* (near-miss) cases. We are applying our results and findings to safety activities in the nuclear power stations. This chapter reports on the methodology used to analyze Hiyari-Hatto cases and on case studies of safety activities in nuclear power stations.

METHODOLOGY FOR ANALYZING HIYARI-HATTO CASES

Heinrich's law states that if an incident has become apparent, there will be many Hiyari-Hatto, or near-miss, cases behind it (Heinrich, Petersen, & Roos, 1980). In 1974, TWA flight 514 crashed near the Dallas Airport. The investigation of the accident revealed that a similar incident had occurred six weeks earlier. This finding led U.S. authorities to establish an Aviation Safety Reporting System for sharing information about near misses, a system that is thought to be useful in the prevention of accidents. We at the TEPCO Human Factors Group likewise believe that it is important to share Hiyari-Hatto cases in order to prevent human errors in nuclear power stations.

Three TEPCO Nuclear Power Stations have been collecting information on Hiyari-Hatto cases, with the aim of preventing human errors. Methods to analyze these cases, however, have not been established. Although various countermeasures are being applied to prevent the recurrence of Hiyari-Hatto cases, most of these countermeasures strongly depend on human attentiveness.

In order to promote safety activities and collect cases effectively, we proposed the m-SHEL model and Hiyari-Hatto Systematic Approach for Error Reduction (H^2-SAFER) procedures. The m-SHEL model provides us with various viewpoints for analyzing Hiyari-Hatto cases. H^2-SAFER procedures provide a systematic and comprehensive approach to analyze those cases.

m-SHEL Model

The m-SHEL model is based on the SHEL model (see Figure 16.1) proposed by Hawkins (1987). The SHEL model explains the relationship between Software, Hardware, the Environment, and coworkers, with a core person situated at the center (Hawkins called this person "Liveware").

The essential point is that the human being (liveware) is at the center of the model; the concept is therefore "human-centered." Another important point is that each element is surrounded by a wavy line. The wavy line of the central liveware denotes the characteristics of a human and the limitations of human abilities. If the line of the central liveware and the lines of hardware, software, environment, and coworkers (liveware) do not match at some points, human error may result. One way to prevent human error is to adjust the line of the core element (liveware) to the other four elements. For instance, if the work requires an overnight shift, one might hire someone who can work overnight or even train workers so that they are able to work at night. On the other hand, the lines of the other four elements can be adjusted to the central liveware. User-friendly manuals and equipment that corresponds to human ergonomics are examples of this strategy.

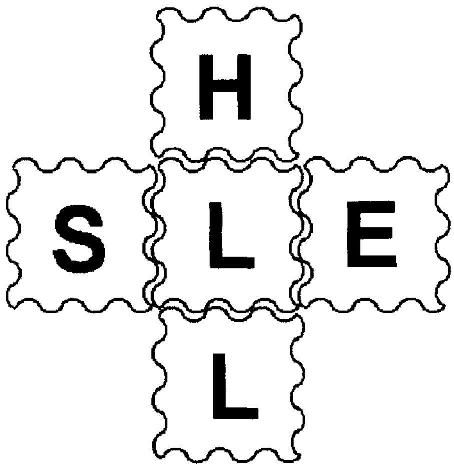

Figure 16.1 The SHEL model.

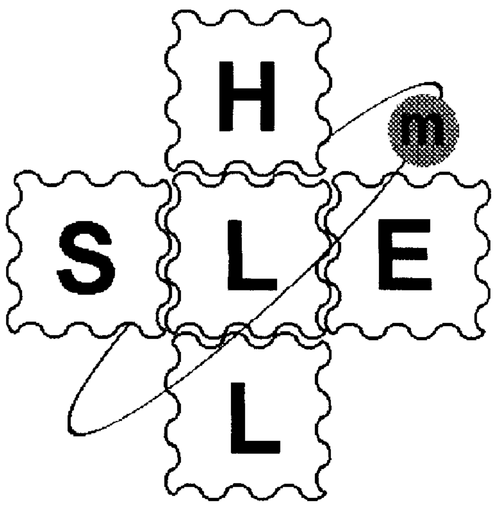

Figure 16.2. The m-SHEL model.

The original SHEL model does not take into account management factors. These factors include organization or administration, company systems, office atmosphere, and a positive environment for the development of safety consciousness. We at the Human Factors Group decided that the management element should stand out from the SHEL model. We have called this revised model the m-SHEL model (see Figure 16.2). Because the management element is related to all other elements, we depicted the management element as a circle that moves around the SHEL.

H^2-SAFER Procedure

Analysis of past accidents shows that accidents are caused by a chain of small events. Each small event has multiple background factors. Often, everyone has some experience with such events.

Based on the points described above, the H^2-SAFER procedure (Yoshizawa, Kawano, & Mutoh, 1997) was developed so that both specialists and operators can analyze incidents and Hiyari-Hatto cases. It is important for operators to understand the structure of a Hiyari-Hatto through their own analysis, not through the analysis of a specialist. This method is based on the variation tree method proposed by Leplat and Rasmussen (1987). The procedure for drawing up a variation tree can be described as follows:

1 Chronologically organize nodes that represent errors in the form of a tree. This tree-making method is based on fault tree analysis; however, because an accident has already occurred, the nodes are connected by *and* junctions only.
2 Search the tree to find out what led up to the accident and what would have prevented it. Then remove the relevant nodes to the accident and cut the links that led up to it.
3 Take appropriate countermeasures with respect to the singled-out nodes and links that led up to the accident by using Rasmussen's (1986) step-ladder model.

When we analyze an incident through the variation tree method, it is difficult to pick out errors from the incident and make a tree by using them exclusively. To analyze the backgrounds of an incident, it is necessary to understand the relationships between the irregular actions as well as among all subsequent flows from the incident. The step-ladder model is one cognitive model of human behavior, but it is difficult for operators to understand and use in their analysis of Hiyari-Hatto cases. The tree in the H^2-SAFER procedure is easier for operators to use and consists of every action in an incident or a Hiyari-Hatto case. We also introduced the m-SHEL model to list problematic actions in the trees rather than adopt the step-ladder model used in the variation tree method. The H^2-SAFER procedure has seven steps:

1 Persons and/or equipment involved in a Hiyari-Hatto case are listed at the top of columns. Each action and statement of the persons and/or equipment is represented chronologically in the form of a tree. We call this tree the Hiyari-Hatto tree (see Figure 16.3). By completing this tree-making step, one can correctly understand the flow of the Hiyari-Hatto event.
2. The problematic actions are picked out from the Hiyari-Hatto tree.

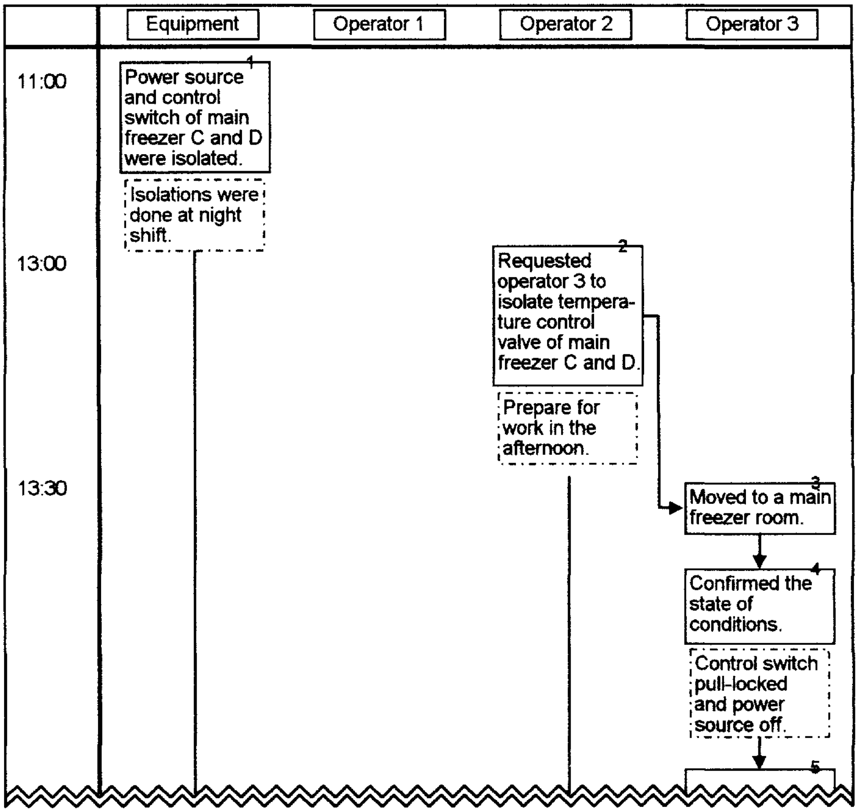

Figure 16.3. An example of a Hiyari Hatto tree.

3. The backgrounds of the problematic actions are analyzed, from the viewpoints of software, hardware, the environment, coworkers, and management, using the m-SHEL model.
4 The countermeasures for each problematic action are listed using the H^2-GUIDE procedure (see Figure 16.4).
5. The best countermeasure is selected.
6. The selected countermeasure is applied.
7 The effect of the applied countermeasure is evaluated. Side effects of the countermeasure are also evaluated.

We also proposed the H^2-GUIDE procedure, a procedure to generate ideas on countermeasures for human error prevention (Kawano, 1999). Most countermeasures depend on human attentiveness, so we thought it necessary to list the various viewpoints and systematically include all ideas and

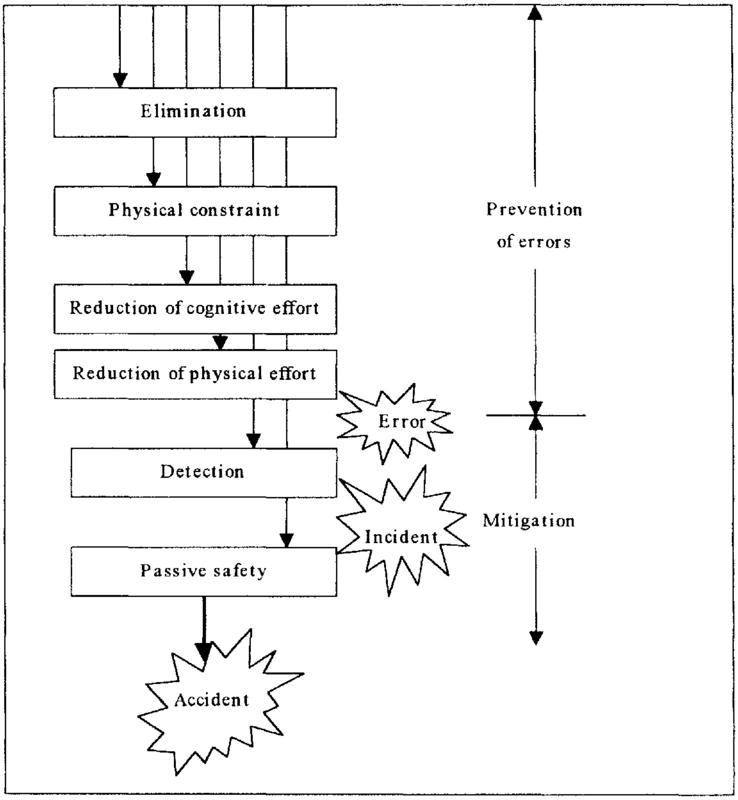

Figure 16.4. The H^2-GUIDE.

perceptions. This procedure has six steps, which are illustrated in Figure 16.4. Countermeasures are listed in the following order because the first step (elimination) is the most effective, followed by all the possible countermeasures: (a) elimination of action that could cause errors; (b) prevention of errors through physical constraints such as interlocks; (c) reduction of cognitive effort, for example by placing a list of work procedures and numerical values in easy-to-spot locations, so that workers do not have to rely on memorization; (d) reduction of physical effort of those who perform in an uncomfortable situation; (e) detection of one's errors and avoidance of these errors before they become incidents; and (f) passive safety, or preventing the incident from proceeding to an accident. The arrangement of this procedure was based on the error-proof technique. It does not include a countermeasure with regard to education, which should be listed after the H^2-GUIDE has been applied.

DIRECT SUPPORT OF NUCLEAR POWER STATIONS

This section reports on the Human Factors Group's support of safety activities using Hiyari-Hatto cases and on a case study of Hiyari-Hatto analysis that took place in the scheduled course of an operator training program.

A Safety Activity for Human Error Prevention Performed in the Kashiwazaki-Kariwa Nuclear Power Station

We support safety activities that prevent human errors at all TEPCO Nuclear Power Stations. In this subsection I report on a safety activity in the Kashiwazaki-Kariwa Nuclear Power Station (KKNPS), which has received our support for the longest period.

Since 1994 the Operation Department of KKNPS has organized a working group to implement an activity for human error prevention. The Operation Department of KKNPS requested the Human Factors Group to be a member of this working group. Because most of the units in KKNPS are the latest models, KKNPS has fewer Hiyari-Hatto cases than TEPCO's older nuclear power stations. This is because at the older stations have been used to implement safety procedures at KKNPS. However, the Operation Department of KKNPS has set up the working group because similar Hiyari-Hatto cases happened several times in the past. Because most operators lack experience in actual major incidents, they take a simulator training course at the Boiling Water Reactor Operator Training Center. In addition to this training, the KKNPS Operation Department used other methods to share the experiences, that is, the Hiyari-Hatto cases.

Five-Stage Action Plan for Using Hiyari-Hatto Cases

The working group of the KKNPS Operation Department has set forth the following objective: "In order to promote a safety conscious environment, each station staff member learns procedures to determine potential causes of human errors and appropriate countermeasures. Each member they has the ability to estimates the results of his particular operation and develops various methods to cope with critical situations." Because developing a safety-conscious mind-set is not an easy matter, the working group members made up a five-stage, step-by-step action plan to promote a safety environment for human error prevention:

1 Sharing of experiences: the first stage of the action plan for prevention of human errors calls for continual collection of information about

Hiyari-Hatto cases. Operators can read the Hiyari-Hatto cases in order to gain virtual experience of such cases and thereby compensate for their lack of experience with them.

2 Identification of factors that cause human errors: operators analyze the Hiyari-Hatto cases from various viewpoints (case study workshop). Case study workshops are held continually to find common causes of Hiyari-Hatto cases.

3 Training in the ability to detect human errors: operators are trained to develop the ability to predict a Hiyari-Hatto situation through their participation in case study workshops.

4 Application of countermeasures: operators develop the ability to come up with countermeasures against the analyzed Hiyari-Hatto cases and apply these countermeasures to the operating procedures and plant equipment.

5 Reflection on design philosophy and operation policy: operators share their countermeasures with plant designers and apply them to the operation guidelines and design guidelines.

A Safety Activity Using the Five-Stage Action Plan

In order to promote a safety activity using the five-stage action plan, the working group first attempted to implement the first and second stages of the plan into the course of everyday work. The working group began with the collection of Hiyari-Hatto cases from operators. They then distributed the collected cases to all operators. The working group prepared a Hiyari-Hatto reporting form to collect information about the causes of Hiyari-Hatto cases and a Hiyari-Hatto analysis form to analyze selected cases.

The information to be collected through the Hiyari-Hatto reporting form includes a title, a description and illustration of the situation, and the reason why the situation did not proceed to a major incident. The reporting is done anonymously. The reporting form has an m-SHEL checklist, with 73 items to consider, that helps operators describe the situation based on the viewpoints provided through the m-SHEL model. A concern with software, for example, might be whether or not the wording in manuals can lead to misunderstandings. With respect to hardware, one concern might be whether or not the arrangement of switches can easily be understood.

The working group also prepared a Hiyari-Hatto analysis form to analyze some selected Hiyari-Hatto cases and to extract the common causes of collected cases. This form addresses two viewpoints: Why did the Hiyari-Hatto event happen, and what kept it from developing into an actual incident? Each viewpoint is analyzed by using the m-SHEL model.

An action plan for the first and second stages was executed. The action plan for the third to fifth stages has not yet been carried out. In the beginning of the activity, about 70 Hiyari-Hatto cases were collected per month, but recently about 30 cases are collected in a year. Six cases were used for case study workshops, and all operation crews analyzed them using the Hiyari-Hatto analysis form. The collected Hiyari-Hatto cases and the results of analyzed cases were fed back to all operators so that they could be shared with others' experiences.

Lessons from the Activity

Hiyari-Hatto cases were voluntary collected, and the number collected was fewer than expected. Most of the cases described only an action, such as mistaking switch button *B* for switch button *A*. The background information on how such a simple mistake had been made was not clearly described.

Two lessons were learned from these case study workshops. One is that when operators picked up on the backgrounds of Hiyari-Hatto cases, they picked up on personal factors and not the other factors, such as hardware or software. The other lesson concerns the methods used in the Hiyari-Hatto case study workshops. There are 36 operation crews in KKNPS, and the results of 36 cases were collected for each case study. It was difficult for the working group to continue case study workshops because there were too many collected cases and it took a great deal of time to summarize them. The workshops then stopped at six case studies. Moreover, when Hiyari-Hatto cases had many problems, the background factors of each problem had to be analyzed separately, but operators had written down all background factors on the same Hiyari-Hatto analysis form. We therefore proposed the H^2-SAFER procedure for case study workshops.

During the course of the safety activity, interviews with operators revealed that the purpose of the safety activity had not been adequately conveyed to the operators. Some operators thought that the Hiyari-Hatto cases were being collected in order to improve research data for the Human Factors Group. Some participants stated that it was embarrassing to talk about one's own errors and that it was a bother to write out Hiyari-Hatto cases on paper. Other participants said that it would not do any good to submit Hiyari-Hatto cases, because this activity would not lead to improvements in the equipment. Reflecting on these opinions, the working group felt that the operators' consciousness of safety was low. The working group therefore needed other methods to promote the activity using Hiyari-Hatto cases, because the Operation Department is not responsible for the improvement of equipment.

During this time, an overflow of a dry-well sump occurred in 1998 during routine maintenance at Unit 1 of KKNPS. The trigger of the incident was a human error, which inspired the superintendent to set up a task force to promote activities for human error prevention. Prior to this incident, the safety activity using Hiyari-Hatto cases was supported only by the Operation Department of KKNPS. Since the incident, task force members have come from all divisions of KKNPS, including the original working group of the

Operation Department. They have continued the safety activity, and the improvement of equipment, which was proposed through the analyzed Hiyari-Hatto cases, has become easier. The working group is promoting the activity using the five-stage action plan based on the task force continuously.

A Case Study of Hiyari-Hatto Analysis in the Scheduled Course of the Operator Training Program

When we considered what support the Human Factors Group could offer, we found that it was necessary to give a lecture to the operators that would help them understand the chain of events and background factors of Hiyari-Hatto cases. Thus, it was decided that a lecture about the Hiyari-Hatto case analysis approach would be given in the scheduled course of the operator training program.

The topics of other lectures include the "Training program for Improvement of team Performance with Scientific methods" (TIPS), which is a training method to improve operators' teamwork, and human behavior in emergency situations and countermeasures for provision. Lectures are given at all nuclear power stations.

Our lecture for operators is based on H^2-SAFER. The lecture emphasizes that each incident consists of a chain of events and that the exploration of the causes of each event and other background factors is essential in order to share Hiyari-Hatto cases. We have received favorable comments from participants, who have stated that they now perceive the existence of a complex chain of events even in apparently simple incidents, which in turn is useful for their operational work. On the other hand, other participants said that it would be an enormous task to analyze all Hiyari-Hatto cases through the H^2-SAFER procedure. We therefore recommend that the H^2-SAFER procedure be used for some important cases and that operators try to always read the backgrounds of the other Hiyari-Hatto cases.

INDIRECT SUPPORT OF NUCLEAR POWER STATIONS

In providing the direct support to nuclear power stations described above, we have started two research activities that are necessary to more effectively promote safety activities. One activity is the development of the Hiyari-Hatto database system via the Intranet system; the other is a case study on High Reliability Organizations (HROs).

Development of the Hiyari-Hatto Database System via the Intranet System

During our human error prevention activities using Hiyari-Hatto cases in nuclear power stations, we received feedback that it is troublesome to write up Hiyari-Hatto cases on paper and that one has to scan all collected cases in order to find the cases that one needs. We then came upon the idea that information could conveniently be shared through a computer database system. TEPCO has an Intranet system, and we are developing a Hiyari-Hatto database system via the Intranet. We are investigating the method to use it effectively as well as the security of data.

We will at first serve this system to the operators and staffs of the Operation Departments at three nuclear power stations. They can retrieve each Hiyari-Hatto case by entering key words. We plan to open this system to all divisions in each station and collect their opinions on how it could be used more effectively.

A CASE STUDY OF HROs

Through our support of the activity of KKNPS and through the lectures given to operators in the operator training program, we found that the following points are quite important in promoting the activities: (a) On-site staffs need to understand the purpose of the activities, (b) the result of the activities should be visible, and (c) the methods must be simple. On the other hand, we would like to find another method to promote an organizational culture that does not commit human errors.

Through our research of organizational factors and methods to share Hiyari-Hatto cases effectively, we found that some organizations, so-called High Reliability Organizations (HROs), were keeping a high level of safety performance. We took notice of and researched these organizations in order to be able to refer good practices.

In our study, we investigated recent studies on HROs and interviewed HROs and organizational safety experts in order to identify the essential characteristics of HROs and uncover some tips for continuing their safety performance. The members of safety-promoting groups from three TEPCO Nuclear Power Stations also participated in this study. We classified the characteristics of HROs into three categories: organization safety policy, continuation of safety activities, and tips for safety. The categories include the following attributes:

1 Organization safety policy

- Top managers of HROs have strong leadership skills and enthusiasm for the activities.
- HROs make responsibilities clear.

2 Continuation of safety activities

- HROs have a concrete model of the activities.
- HROs use simple and effective methods.

3 Tips for safety

- Consciousness of "we are not safe enough" is present.
- Workers execute what they can do by themselves.

We learned that for the continuation of safety activities, the most important things are the strong determination of top managers to execute the activities and the actual execution of the activities by the on-site staff. Top managers also gave timely feedback on countermeasures, tried various and simple methods, and adopted various techniques and made them part of everyday work. We made up a pamphlet based on these tips and distributed it to all nuclear power station staffs and contractors.

The Internal Committee on Climate Improvement was established in TEPCO as a result of the falsified manufacturing data scandal relating to a transport flask of spent nuclear fuel, an event that occurred through a subsidiary company last autumn. The committee examined the problem, which involved the cultural climate in TEPCO. Nuclear power stations also have started many activities based on the investigation results of the committee.

CONCLUSION

The Human Factors Group of TEPCO's Nuclear Power Research & Development Center joined up with three TEPCO Nuclear Power Stations to support safety activities that prevent human error. In supporting these activities and investigating HROs, we found that the most important things are the strong determination of top managers to execute safety activities, the actual execution of the activities by on-site staffs, and the systematization of the activities into everyday work.

We at the Human Factors group maintain that continuous safety activities lead to the prevention of human errors and the deepening of on-site staffs' safety consciousness. We believe that when safety consciousness is raised, potential errors can be discovered before actual human errors are made. We will continue to support the safety activities in nuclear power stations by providing our lectures and lessons according to the individual needs and situations of each station.

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CHAPTER SEVENTEEN
Enhanced Activities for Human Error Prevention at the Kansai Electric Power Company Nuclear Power Stations

HIROSHI SAKUDA

Among the most important activities for human error prevention, the first is to build an organizational structure and climate that exclude or scarcely permit the occurrence of human errors. This objective requires activities to counter potential events, that is, Hiyari-Hatto activities (near-miss activities). The second activity is to investigate thoroughly the cause of human error, if it led to an unfortunate outcome, and to take actions to prevent its recurrence. This objective requires activities to counter the events experienced, that is, event analysis. The third activity involves education to enhance human factor awareness of the personnel working in the field. In order to make these activities effective, joint activity between our company (KEPCO) and the subcontractors is important. This chapter also includes a description of activities performed from such a joint approach.

THE HIYARI-HATTO ACTIVITY

The Hiyari-Hatto activity is based on Heinrich's Law, proposed by the U.S. safety engineer H.W.Heinrich in 1959, which defines the possibility of a major casualty occurring. According to this law, behind one major casualty there are 29 small casualties and some 300 experiences of Hiyari-Hatto events (near-miss events). Hiyari-Hatto events (near-miss events; literally translated from Japanese, "startle" or "cold sweat" events) are said to be the seeds of casualty, and they derive from the same causes as accidents do. Whether or not a particular Hiyari-Hatto becomes a casualty is only an indirect result of chance.

Performed by small groups, the so-called Hiyari-Hatto activity is a voluntary activity for casualty prevention. In this activity, importance is attached to the following goals rather than to casualty as the outcome: (a) devoting attention to the Hiyari-Hatto event itself; (b) recording, discovering, and being aware of Hiyari-Hatto situations; and (c) mutually making each other aware of a potential problem, behaving in ways that promote safety, and eliminating unsafe points. This approach is also applied in human error prevention activities.

During the initial period, activities by the Wakasa district office were limited to encouraging the small groups in the stations to present examples of Hiyari-Hatto events. Later, when the number of event examples being presented decreased, the issues regarding the activity were reviewed and their countermeasures were discussed. In addition to establishing an appropriate corporate standard in order to once again activate the activities, including reporting to the branch office, the activities were expanded to the holding of round-table conferences and lectures on Hiyari-Hatto activities and the invitation and special recognition of posters and watchwords.

Since then the number of examples presented temporarily increased; however, there were indications that the number was again decreasing, which led to the decision to evaluate the activity up to that time through quantitative and qualitative analysis. The evaluation would also serve the purpose of utilization of event samples. The results of this evaluation showed that although each group had understood the importance of the activity well and performed the activity with a constructive attitude, the number of event reports filled out had decreased because of troubles with fitting a description of the event to the prescribed format, which required report submittal and imposed a great deal of paperwork. It was then decided that the activity should no longer require general, broad participation but should be resumed with a new strategy: reorienting the activity so that each small group could voluntarily and easily perform it. The corporate standard was revised accordingly and has been followed since then.

Analysis of Reported Events

Development of the Analytical Method

The conventional method of event analysis places importance on "what happened," centers discussion on aspects of the outcome, and tends to conclude that workers were not careful enough. However, based on the view that humans do not commit error deliberately, the need for a method suitable for analysis of "why it happened" became evident. Methods of this kind have already been developed, such as the Human Performance Evaluation System developed in the United States and some other methods developed in Japan. However, many problems with these methods arise when nonexpert people use them for voluntary purposes in the work field for just a limited time.

We in the KEPCO Nuclear Quality Control Center therefore developed a method that is easy to use in the work field and suitable for analysis from the viewpoint of human factors. As shown in Figure 17.1, our analytical method employs fault tree analysis, which is based on a model by Rasmussen et al.

(1981) for describing the process of error occurrence. The mode of human error, information-processing steps by humans, and external and internal factors are designated, respectively, as the top event, middle event, and basic event. The fault tree diagram for human error occurrence was developed using the "conscious phase" classificatory scheme proposed by Hashimoto (1981) for the internal factors and the "4M" (Machine, Media, Man [Person], and Management) classificatory scheme for the external factors (see Table 17.1). Since its completion in 1987, this analytical method has been applied for the analysis of events that have occurred in nuclear power stations, including injuries to workers.

Analysis of and Countermeasures Against Experienced Events

The analysis of an event is performed by a study group consisting of the persons having detailed knowledge of the event (or job) and persons in an appropriate position to represent the views of a third party. All members of the study group are personnel of the site of event occurrence (the power station), with the exception of branch office personnel who advise on how to use the fault tree diagram for human error occurrence. The duration of the study varies according to the nature of the event; one to two months is usually needed.

The steps taken in the analysis are illustrated in Figure 17.2. The first step of the analysis involves listening to relevant persons try to clarify the process of event occurrence in chronological order so that the crucial points of the issue can be identified. These identified points are then designated as the top events for understanding what kind of error mode was made to cause the event and which stage of information processing came under this event. This step also helps in understanding internal and external human factors that lead to such error mode.

In general, relatively accurate and effective results are obtained through human factor analysis if it is performed by a professional third-party group. Yet, although an analysis performed by site personnel is not expected to generate results as objective as those produced by a professional group, a practical human factor analysis has been achievable because an analysis based on understanding the complete details of the field condition is possible.

Countermeasures against the identified internal and external factors are selected through classification by foolproof principles and then are evaluated for their importance and examined for further application to other power plants. Classification by foolproof principles means pursuing countermeasures against the identified factors from the viewpoints of (a) exclusion, (b) use of alternatives, (c) making implementation of workers'

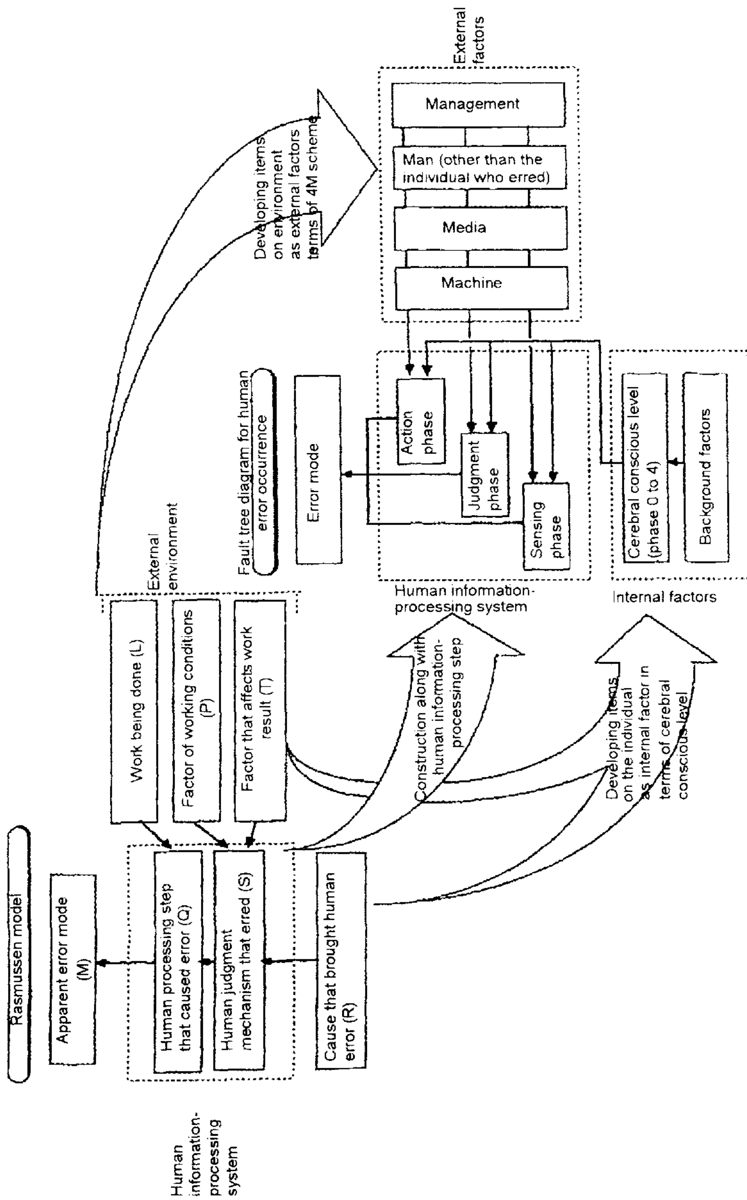

Figure 17.1 Relation between Rasmussen model and the method developed at Kansai Electric Power Company

tasks easier, (d) anomaly detection, and (e) consequence mitigation. As far as possible, countermeasures with younger number should be selected.

Table 17.1 Classification of Internal and External Factors

Internal factors		External factors	
Phase 0	Unconsciousness	Machine	*Man–machine interface *Equipment layout *Work environment, etc.
Phase I	Subnormal	Media	*Manuals *Procedures *Check sheets, etc.
Phase II	Normal, relaxed	Man (person)	*Physical condition *Psychological, mental condition *Capability, etc.
Phase III	Normal, clear	Management	*Organization *Education, training *Safety management, etc.
Phase IV	Hypernormal, excited		

Systematic Training on Human Factors

A number of incidents occurred in a row in 1986 at KEPCO; these incidents originated from human factors and led to a mood of crisis among all personnel concerned. Technical and engineering training curriculum since then has included issues on the importance of human factors and has been revised regularly. As indicated in Figure 18.4, present curriculum consists of three courses for achieving an advanced stage of safety culture.

Database Accumulation of Events Experienced

There were not enough documents available with respect to actual events, such as accidents or failures experienced in the past, that were accordingly adapted for training and educational purposes. It therefore did not suffice to utilize the lessons to be gained from past events. Events studied analytically with the help of the fault tree diagram for human error occurrence were accordingly edited for the learning text and called "lessons from events". The text illustrates, for example, why an incident occurred or what was the real issue of an event, so that past experiences can be more easily understood.

The "lessons from events" learning texts are available to all company personnel through the computer network, and anyone can access any of the past negative events at any time for purposes of self-learning. This valuable "negative inheritance" has also been fully utilized and transferred to personnel in workshop training or recruitment training.

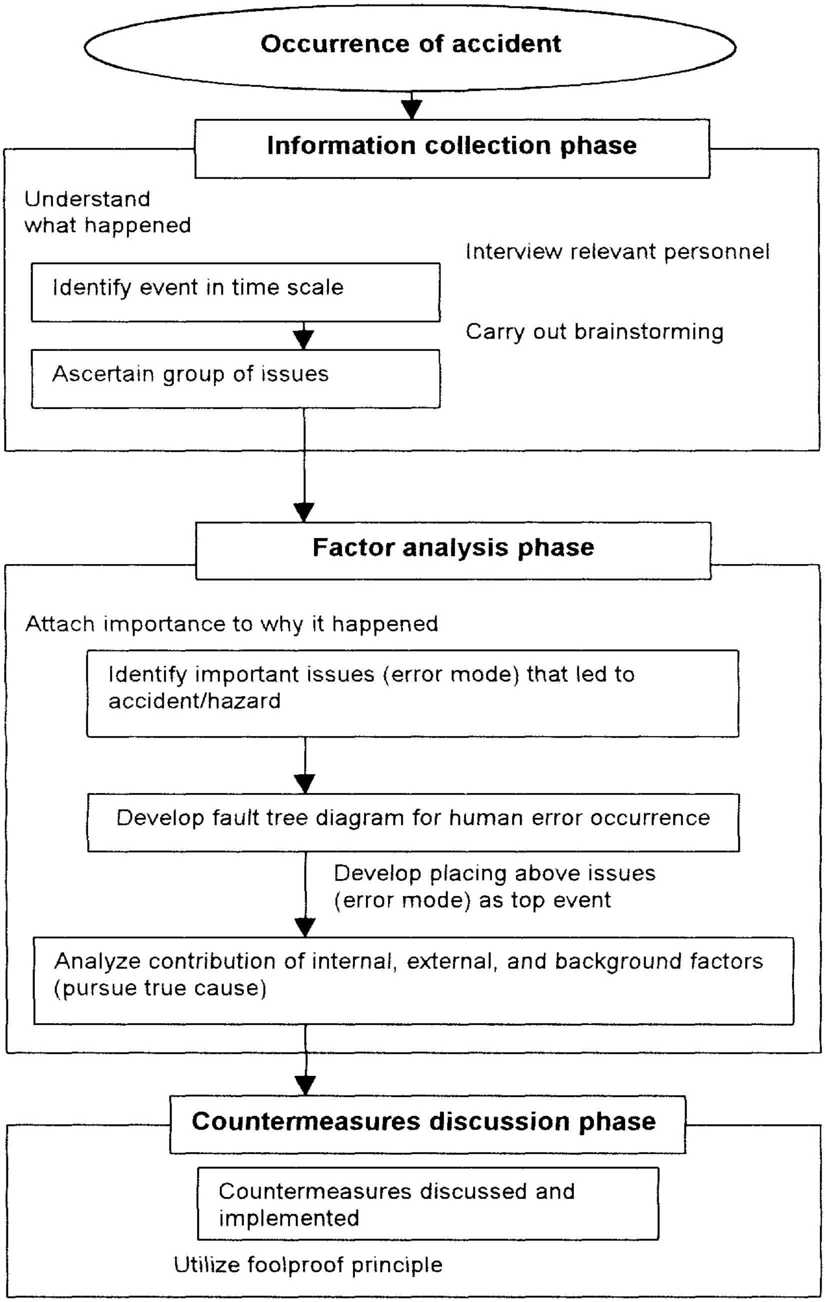

Figure 17.2 Flow of a Kansai Electric Power Company analysis

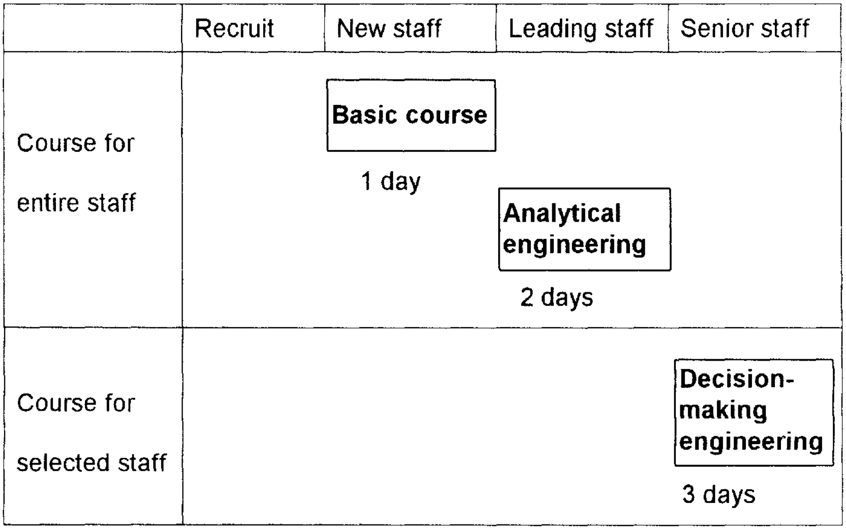

Figure 17.3 Training system for human factors (for fiscal year 1999)

Basic Course on Human Factors

The basic course is for operators, maintenance workers, and so forth. It is necessary that all staff know how human characteristics and behavior relate to human error and why routine tools, such as calling loudly while pointing at the object, toolbox meetings, procedures, and communication, are required for the prevention of human errors. In addition, staff should be given enough knowledge to understand the content of human factor information. This course is accordingly prepared to enable participants to learn and master basic knowledge of human factors.

The practice of calling loudly while pointing at the object is performed in cases like the following: When standing before the water-level meter of a steam generator, a worker points his or her finger at the meter and calls in a loud voice, “Steam generator water level is 44%! No anomaly!” It is said that calling loudly while pointing at the object has the following four effects: (a) cerebral activation (a broad gesture and loud voice stimulate the brain), (b) temporary cessation of a series of action (redirecting attention through temporarily stopping habitual actions), (c) mutual communication between workers (the call’s content is given meaning for mutual communication), and (d) memory-strengthening (a memory tends to last when accompanied by a simultaneous broad gesture or other action).

A toolbox meeting takes place every day before the start of work in order to transmit items requiring caution and particular aspects of tasks for the day. Three important objectives are achieved in these meetings: (a) transmitting the contents of a task and role allocation, (b) transmitting the reasons for the directions (prohibited items, etc.), and (c) carrying out a repeated call and confirmation with all members.

Analytical Engineering Course on Human Factors

When an incident that originated from human factors has occurred, the power station must recognize the issues pertaining to the event and then consider and decide on what countermeasures are needed. Therefore, each department in a power station is required to have several persons who know how to perform event analysis. This course has been prepared in order to respond to such a need.

In particular, the course participants are provided with a particular event process and the information obtained through the oral statement given by a relevant person, on the human error occurrence. They are then instructed to find the root cause of the event through using the fault tree diagram for human error occurrence (explained in the section on development of the analytical method) and to develop a plan of necessary countermeasures. Presentation of each group's results and an exchange of opinions between the groups are then made in order to gain new points of view and brush up on analytical engineering capabilities.

In the actual analysis of human error, personnel who have taken this course participate in the analysis, as do the branch office personnel who are required to participate.

Decision-Making Engineering Course on Human Factors

In the past, the cause of an incident was more or less attributed to an "error in judgment": management simply inferred from the result and scolded the individuals in charge. Staff participating in the decision-making engineering course are encouraged to share with each other their understanding of what "judgment" and "error in judgment" mean. In addition, through examples of event analysis, participants are taught to understand the importance of the process leading to a judgment. This course therefore aims to have individual staff members recognize the importance of thinking by themselves in order to "become aware" of how to act and thereby prevent human error.

This course, as well as the analytical engineering course on human factors, focuses on event study and group discussion. Here is an example of a course exercise: Mr. A came to a market to shop, but he needed to go home within 30 minutes. There were a few counters open, but each of them had some customers waiting. Mr. A chose the second counter and had to spend more than 30 minutes as a result. In this case, did Mr. A err in judgment or not?

In the actual training, more information is given than that provided here, and a thorough discussion is held on whether or not Mr. A's tardiness should be attributed to an error in judgment on his part because he did not take into consideration that the counter staff was undertrained or the fact that the customer waiting before him was buying an item that needed to be wrapped.

Studies Related to Human Factors

Development of Methods for Operator Teamwork Training

The core of the activities for human error prevention has concentrated in the past on the education and training of individuals. To further enrich these activities, an organization's systematic approach must be extended beyond conventional individual training. This strategy is best realized through pursuing a teamwork approach to the prevention of human errors.

Because operators at a power station perform their duties as one team, the development of this approach began with studies of operator functions. For an operator, teamwork is an essential aspect of his or her duties; yet what can serve as an indicator for evaluating teamwork is still a matter to be resolved. Hence, a study aimed at finding a clear indicator for the evaluation of teamwork is being carried out, and guidelines for education and training that could help improve teamwork are being researched. The results of these studies shall be used to objectively evaluate the results of training with regard to teamwork; this evaluation will take place at the assessment meeting to be held after the operator family training provided by the Nuclear Training Center.

Development of Animation Tools

Animation tools have been developed as an educational tool for nuclear power plant personnel in order to illustrate overhaul and assembly procedures and complicated mechanisms of equipment and components. The number of animated educational software has been increased through the use of this tool so that the smooth transfer of technology through on-the-job training can be efficiently achieved. Animated educational software has been developed by the branch office; at present, maintenance experts at power stations are actively participating in the development process in order to contribute their expert know-how.

Other Activities

Preparation of Advice Sheet for Toolbox Meeting

Lessons obtained from actual events occurring in power plants and originating from human factors must be openly shared among plant workers, and the key points for preventing recurrence of similar events must be clearly indicated. In order to assist these efforts, an advice sheet with simple illustrations is prepared and distributed within the company and to the cooperating companies. This sheet can be used as educational material at the toolbox meetings and at the round-table discussion in workshops. The design of the sheet is the same as that of the "lessons from events" learning text described in the previous section on database accumulation of events experienced.

Database for Maintenance Events

Past events that are related to plant maintenance have been recorded as a "negative inheritance." KEPCO's Nuclear Power Plant Maintenance Training Center summarizes such events within illustration panels. The illustrated event panels are posted and are also accumulated in the database of the corporate network server so that workers can check them in a timely manner before starting work and so that prior safety confirmation can be easily made.

Educational Videotapes for Human Error Prevention

Of the past events originating from human factors, some require further reinforcement of quality control for the subcontractors. Videotapes that draw in viewer participation and that have a menu of discussions on the point of issue and countermeasures have been created for this purpose. Utilized for educational purposes, these videotapes include ones for newcomers to a power station and ones used at the quality control conference that is organized by the subcontractors working in power stations.

Human Factor Lectures and Sending Lecturers for Site Field Training

To foster safety culture in power stations, site field activity must be activated. Human factor lectures are prepared through selecting lectures from academic and industrial experts from the nuclear power industry and other industries. In addition, for the site field training in power plants, lecturers are sent from the Wakasa district office, which overviews power stations, so that the core personnel for introducing human factor activities at the power station and site field is well trained. This activity is independent from the systematic training on human factors explained in a preceding section.

Figure 17.4 The design promoting human factor awareness

Designated Month for Human Error Eradication

To keep up satisfactory operation of a power plant, human error prevention activities are required in order to continue the integrated efforts that KEPCO and its subcontractors make together. Hence, since 1997 the Wakasa district office and power stations have carried out the following activity: Every year a complete month has been designated for human error eradication in order to enhance further awareness of the importance of eradicating human errors and to activate the human factor improvement activities of each site. The aims of these activities are pursued through various events held during the month, such as the following:

1 Design promoting human factor awareness: the designated activity month is implemented each year. The design best promoting this activity was publicized; in addition, other excellent designs were recognized as well as used in subsequent events (cf. Figure 17.4).
2 Quiz answers and ideas about human factors: a call for answers to a simple quiz on human factors is widely publicized, and prizes are presented to those whose names have been drawn from the pool of respondents correctly answering the questions. A call for ideas on reducing human errors is also publicized. In order to enhance human factor awareness, excellent applications are recognized and referred widely both within KEPCO and to the subcontractors.
3 Distribution of STAR card: since the institution of the month designated for human error eradication, the slogan has been “You are a STAR! Stop human errors!” A STAR card (see Figure 17.5) is distributed to all KEPCO personnel and to the subcontractors on the first day of the designated month. Each employee keeps this card in a breast pocket for the duration of the designated month and attempts to achieve the action objective that he or she has indicated.

STAR stands for "Stop, Think, Act, Review" and is used by the Institute of Nuclear Power Operations in the United States to promote self-checking.

S: check that equipment and components are in proper working condition
T: review action intended and results expected
A: act as intended
R: check results with expected results

Based on this concept of STAR, please write down your action objective here.

Figure 17.5 The STAR card: a human error prevention activity

TASKS FOR THE FUTURE

Based on the activities performed and the experiences collected, we at the KEPCO Nuclear Power Department consider the following aims to be necessary for the future:

1. Activation of risk anticipation activities: efforts should be made to foster a frame of mind that regards events in other stations as if they were in one's own station, thereby creating an atmosphere in which deliberate action prevails in human factor improvement activities, including Hiyari-Hatto activities.
2. Implementation of countermeasures for prevention of stagnation in human factor improvement activities: because their true effects are not directly visible, human factor improvement activities tend to fall into stagnation, so that the improvement of human factor awareness can easily deteriorate. Measures for stagnation prevention should be implemented, and cases with good results should be referred to various places inside and outside the organization.

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CHAPTER EIGHTEEN

Sharing Knowledge on Human Error Prevention

TETSUYA TSUKADA AND FUMIO KOTANI

To prevent human errors during operations on the actual work site, it is important that workers have sufficient knowledge of "the most suitable error prevention methods for different situations." For this reason, it is necessary that all workers develop and share a common knowledge and understanding of the causes and remedies of specific problems, through analysis of past records of problems and cold shiver incidents. Moreover, because of natural limitations in human concentration abilities, it is also important that at critical times workers "call attention" not only to themselves but also to others. They also need to choose more effective methods of calling attention, taking into consideration the intended effect of the method and the appropriate situations for using the method. In addition, for the sake of organization, it is desirable that workers develop a consensus on "fundamental safety concepts" by means of effective communication. In response to these needs, INSS is promoting the investigation of a database system that permits two-way data communications on our intranet, in order to establish an organization in which all workers share a common knowledge base. This accumulation of a large store of the collective know-how of field workers on the prevention of human interface errors will help to minimize errors.

Of the conceptual models of human errors, Hawkin's (1991) Software-Hardware-Environment-Liveware model (SHEL model) is well known. The domain of the individual human (Liveware) is located in the center of the SHEL model. This domain is then surrounded by the domain of factors related to human factors, namely, standards (Software), facilities (Hardware), work environment (Environment), and the domain of humans concerned other than the individual in the center (Liveware). According to this model, human errors are caused by an adjustment between the individual in the center and the surrounding factors related to human factors.

Conventional measures to prevent human errors have focused on standards, facilities, and the work environment in order to achieve improvements in this outer domain, and the number of human errors has decreased. The domain of factors directly related to humans, however, includes an individual human, the humans surrounding the individual, an organization, and management of the organization. And, more specifically, this domain is the one in which humans relate with one another, for example through communication, leadership, and the climate and culture of the organization. Because it is difficult to adopt preventive measures in this domain, few improvements have been made so far. To improve on current human error prevention, it is necessary to work out measures with a focus on the domain of the individual human, the organization, and management of the organization as well as continue to apply measures dealing with standards, facilities, and the work environment.

Members of an organization can reach objective agreement on a particular issue through communication. An objective agreement involves a way of thinking, behavioral patterns, and implicit norms (referred to as climate or culture) that are dominant in a company or workplace and shared by the majority of employees, such as "decision-making and communication which are particular to the workplace" and "how human relations should be" (Robbins, 1997; Watanabe, 1997). Ways of thinking about and behavioral patterns toward safety are included in organizational climate and culture, and if there is insufficient communication in an organization, the climate and culture related to safety will not be shared. Such an organization may lose control over its members and face increased risks of human errors because of unsafe behaviors and failure to comply with safety rules. To create an organization in which human errors are not likely to happen, it is important to ensure smooth communication within the organization as well as a safety climate and safety culture that are shared by all members.

On the other hand, the individual at the center of the SHEL model becomes directly involved in human errors during operations on the actual work site. Even if the individual performs his or her job with the utmost care in order to not cause any errors, an error can occur unless the individual correctly responds to the actual situation at that particular moment, for facilities, the environment, and other conditions around the individual are constantly changing. Prevention of an error requires that each person know as many measures as possible in order to successfully deal with each situation. Furthermore, because humans' attentiveness cannot be sustained for a long time, it is important that each person "signal the attention" of himself and others to the prevention of errors in a timely manner.

Table 18.1 Numbers of Incidents and Human Errors in Japanese Nuclear Power Plants, 1981–1997

	Business Year							
Item	1981	1982	1983	1984	1985	1986	1987	1988
Number of incidents	3.2	2.8	2.8	1.4	1.3	1.4	1.2	1.3
Number of human errors	0.8	0.5	0.4	0.5	0.4	0.3	0.3	0.2

Item	1989	1990	1991	1992	1993	1994	1995	1996	1997
Number of incidents	1.0	0.9	0.6	0.8	0.5	0.4	0.6	0.4	0.5
Number of human errors	0.2	0.3	0.1	0.1	0.1	0.1	0.2	0.1	0.1

Note. This table was developed based on the data provided by the Agency of Natural Resources and Energy Web site (http://www.enecho.go.jp/index02.html).

OCCURRENCE OF HUMAN ERRORS IN RECENT YEARS

Table 18.1 shows the total number of incidents and human errors that occurred each year from 1981 to 1997 in Japanese nuclear power plants. Nuclear power plants have endeavored to prevent human errors from happening. Such efforts contributed to a gradual decrease from the 1980s to the 1990s in the number of incidents caused by human errors in Japanese nuclear power plants. In recent years, however, the numbers have remained almost the same, and incidents have occurred almost every year, though the numbers have remained low.

What should not be overlooked is that there is a strong likelihood for rare incidents caused by human errors to lead to shutdown. As can be seen in Table 18.2, of the 97 cases of incidents caused by factors other than human errors (including factors related to facilities) during operations from 1990 through 1997, 58 cases (60%) led to shutdown. In comparison, 33 (75%) of the 44 cases of incidents caused by human errors led to shutdown, though the total number of incidents was lower. Thus, incidents caused by human factors are very likely to cause shutdown and have great implications for society. The prevention of incidents caused by human errors is therefore of grave importance from the viewpoint of nuclear power plant safety.

ORGANIZATION, MANAGEMENT, AND PREVENTION OF HUMAN ERRORS

Watanabe (1996) developed a model by sorting out both various factors behind the human errors that individuals made in the actual operation of railways and unsafe behaviors at the actual work sites. Figure 18.1 shows our

Table 18.2 Human Errors and Shutdown, 1990–1997

Causes of incidents	Number	Number of incidents during operation (A)	Number of incidents leading to shutdown (B)	Ratio (B/A) %
Human error	48	44	33	75
Other than human error	162	97	58	60
Total	210	141	91	65

Note. This table was developed based on the data provided by the Agency of Natural Resources and Energy Web site (http://www.enecho.go.jp/index02.html).

structural model of human error prevention, which was worked out by adjusting Watanabe's (1996) model to the actual operation of power plants and by adding the items "knowledge of cases of incidents and near incidents" and "measures to call attention," both of which are significant factors in the prevention of human errors.

We have found that many of the conventional human error prevention measures serve as nothing more than a kind of symptomatic therapy to patch over a problem when it arises. Because the mechanism of human errors is highly complicated, these conventional measures attribute human errors to relatively understandable causes, such as facilities, equipment, and the environment as well as attitudes, awareness, and the nature of individual humans. As a result, measures to improve the facilities in question were adopted, which is of course good, but in the domain of software they tended to concentrate on adding prohibitions and providing education on safety knowledge. Watanabe (1996) wrote that it is not a wise policy to attribute errors to superficial facilities and equipment or to carelessness of individuals, nor is it wise to adopt measures that function like symptomatic therapy, for these strategies may dampen the motivation of individuals.

As can be seen in Figure 18.1, the factors involving humans are safe behavior, which prevents human errors from occurring in the first place, and safety awareness, which is basic attitudes toward safety as well as the motivation that supports safety awareness. To enhance safety awareness, it is necessary for individuals to be highly motivated to do the work. If there are factors to crush motivation, then safety awareness can never be heightened.

This last point can be explained as follows. For an operator engaging in actual work, safety activities in themselves do not directly bring him a reward. And, without the motivation of a reward to do his job, it is unrealistic to expect a strong commitment to safety activities from him. However, even in the absence of a direct reward, six factors do determine the level of motivation: facilities and environment, how to handle work, climate and culture of the workplace, the organization and institution, technical expertise and skill, and the nature of the individual (see Figure 18.1). The basic concept of safety is also a factor in that it underlies the six factors and serves as the

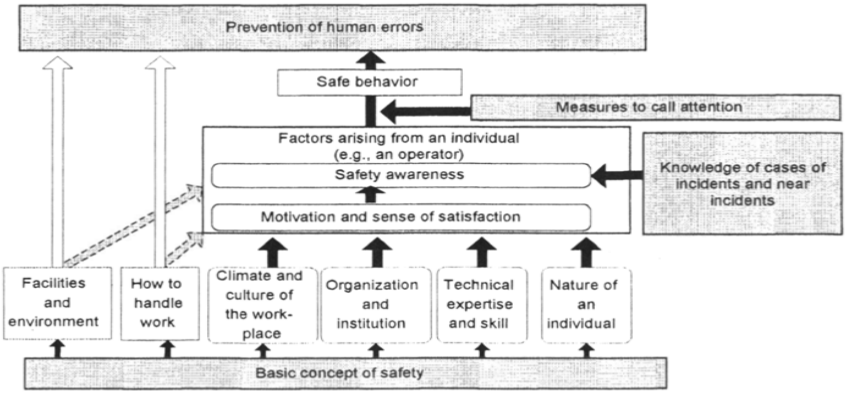

Figure 18.1 A structural model of human error prevention.

norm for them. The levels of individuals' motivation are thought to depend on how individuals evaluate these seven factors, that is, whether they are satisfied with them or think that there are problems with them. Furthermore, all seven of these factors directly relate to the problem of management. For an organization to manage these factors and maintain a high level of safety awareness among individuals, it is desirable not only to make efforts to eliminate the factors that dampen motivation. Rather, it is also important to agree on and share a basic concept of safety that provides the norm for communication about the factors among organizational members through official channels (i.e., operational communication routes connecting the posts in the organization) and unofficial channels (i.e., personal relations apart from these posts).

AGREEING ON AND SHARING A BASIC CONCEPT OF SAFETY WITHIN THE ORGANIZATION

In our attempt to provide a method for reaching agreement on a basic concept of safety and sharing this concept throughout the organization by means of official channels, we have developed a model that serves as an objective check of whether safety awareness is sustained and illustrates how to spread safety awareness throughout work sites (see Figure 18.2).

As illustrated in this model, in order to enhance the motivation of individuals and maintain and heighten safety awareness continuously, the top of the organization (director of the power plant) who actually engages in the operations should declare the organization's safety policies and continually communicate them to the operators. The means of communication are through official channels: regular meetings with superintendents, in which the top conveys the policies to them. Then, once the policies have been clarified by the top, the superintendents should carry out safety measures in

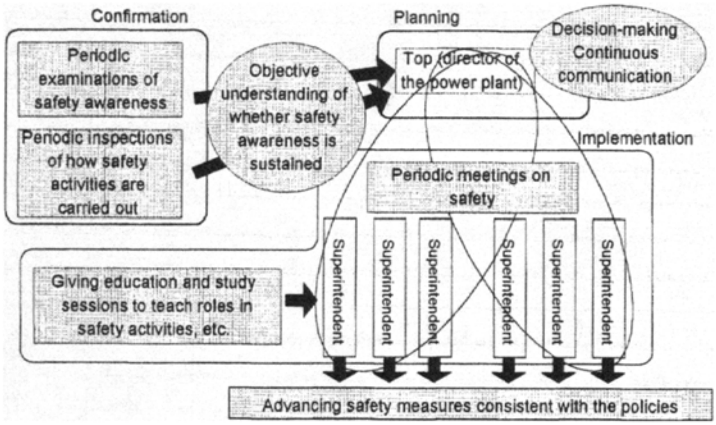

Figure 18.2 An objective check of whether safety awareness is sustained and how to spread safety awareness throughout work sites.

their own work sites. It is important at this point that the superintendents fully understand their roles in and methodologies for pursuing the policies. If a superintendent does not have enough ability to carry out the policies, then the top's policies may not assimilate into the superintendent's work site. Therefore, superintendents should receive education and study sessions about their roles in safety activities, if necessary. By periodically conducting safety awareness surveys and safety activity checks, the top should be able to grasp how his or her policies are actually followed and use this information in planning the next development.

Through intensive implementation of the activities on a top-down basis, a consensus on the basic concept of safety may be reached and shared throughout the organization in a relatively short time.

KNOWLEDGE OF INCIDENTS AND NEAR INCIDENTS EXPERIENCED BY INDIVIDUAL OPERATORS

For individuals to prevent human errors on their own, they need to have knowledge of as many measures as possible so that they can correctly deal with potential situations. Individuals can acquire such knowledge through learning about cases of incidents and near incidents experienced by their predecessors during their actual work. There are, however, a variety of work sites and potential situations that may bring about utterly new incidents and near incidents that no one has ever experienced. It is therefore important that cases of incidents and near incidents experienced by individuals be shared as common knowledge with all operators.

A near incident is a case in which some development occurred in the course of daily operations, before the operator noticed it and stopped it from developing any further; had the case developed further, it could have hurt the operator or caused some incidents. Near incidents provide precious opportunities for discovering dangerous spots, hidden in the actual power plants and operational procedures, that might cause incidents. Once someone has experienced a near incident, it is important that the operators and organizational members learn a lesson from it and make efforts to not allow the near incident to happen again.

At an organizational level, the prevention of hazards and incidents can be furthered by eliminating potential risks through analyzing reported near incidents, working out measures to be taken to respond to the incidents, and improving all the places that seem susceptible to similar incidents in terms of both hardware and software. However, in actual power plants with their great number of machines and equipment arranged in a complicated manner, it is virtually impossible to take immediate measures to cope with every near incident, though such steps are desirable. Because a hazard or incident is thought to be caused by a chain of several small events, but a near incident is something that is still at a stage before a small event arises, lower priority tends to be given to near incidents for reasons of cost-effectiveness, except for those events a short chain of which could potentially cause a grave hazard or incident. As a result, similar near incidents come to be experienced by other operators in other areas. Hence, to prevent hazards and incidents from occurring in any areas, including those areas in which preventive measures have not been taken, it is important to share as common knowledge and with all operators in the plant every near incident experienced by a single operator. Knowledge that "there has been such a near incident in that place" or that "such a near incident has happened during that operation" helps curb the occurrence of similar near incidents.

With a small number of tangible injuries and incidents, power plants have been collecting cases of near incidents in order to develop measures that prevent hazards and incidents. The machines and equipment in a power plant are maintained by the power company itself and many contractors (contractors, subcontractors, etc.). Contractors tend to take a quality-related near incident that occurs during their contracted operation as an indication that they have only a low level of skill. Therefore, when a work team submits a near incident report sheet to the outside, it considers every kind of evaluation that may be made of the group by outside evaluators and obtains approval from higher management before submitting the report. Such negative images of near incidents induce the writers of reports to deal with only harmless incidents, using expressions such as "slipped" and "stumbled." As a result, the reports do not provide information that is useful in grasping the inner meaning of errors.

Table 18.3 An Example of Aggregation and Correlational Analyses of "Error Mode and Mechanism Item" x "Work Description Item"

Work description / Error item	Total	Operations 1 Plant start-up operation	2 Plant output and operation monitoring operations	3 Regular testing operations	4 Inspections during abnormalities	5 Plant shut-down operations	6 Auxiliary equipment start-up and shut-down operations	7 Auxiliary equipment regular switch-over operations	8 Trial-run operations	9 Isolation and isolation restoration operations	Maintenance 10 Surveillance inspections	11 Disassembly inspection work	12 Part replacement and repair work
Error modes													
Omission													
81 Omission of an entire job	0.3	0.0	0.0	0.0	0.0	0.0	2.6	0.0	0.0	0.0	0.0	0.0	0.0
82 Omission of a part of job	5.3	11.1	4.3	0.0	0.0	0.0	7.7	0.0	0.0	2.1	25.0	6.6	10.0
83 Omission of confirmation action	87.4	66.7	86.2	93.8	92.3	100.0	87.2	100.0	75.0	93.8'	62.5	88.6	80.0
84 Omission of correspondence or instructions	1.1	0.0	1.1	0.0	0.0	0.0	0.0	0.0	25.0	0.0	0.0	1.2	10.0
Commission (unreliable execution)													
91 Error in work (too much or too little)	1.0	11.1	3.2	6.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
92 Error in settings (too much or too little)	0.1	11.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

94 Operation timing error	0.3	0.0	0.0	0.0	7.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
95 Incorrect selection of equipment or parts	50.0	22.2	55.3	56.2	46.2	100.0	66.7[+]	70.6	75.0	56.2	12.5	47.3	40.0
96 Wrong position or location	33.2	44.4	29.8	18.8	38.5	0.0	15.4-	29.4	25.0	36.1	62.5	37.1	50.0
97 Procedural errors	3.1	0.0	2.1	12.5	7.7	0.0	7.7	0.0	0.0	2.1	12.5	3.0	0.0
98 Errors in correspondence or instructions	2.7	11.1	3.2	0.0	0.0	0.0	5.1	0.0	0.0	0.7	0.0	0.6	0.0
99 Insufficient quality	6.4	0.0	3.2	6.2	0.0	0.0	2.6	0.0	0.0	2.8	12.5	8.4	10.0
Commission (execution of unrelated actions)													
A1 Execution of unscheduled work	2.1	0.0	2.1	0.0	15.4	0.0	2.6	0.0	0.0	2.1	0.0	0.6	10.0
A2 Fall or incorrect contact	1.7	0.0	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4	0.0
Error mechanisms													
Detection of information													
B1 Overlooking trigger information	0.8	0.0	1.1	0.0	7.7	0.0	2.6	0.0	0.0	2.1	0.0	0.0	0.0
B2 Loss of intent	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0
Errors based on skill													
C1 Lack of detection of situation due to habituation	23.3	0.0	28.7	31.2	7.7	100.0[']	38.5[']	41.2	50.0	22.9	0.0	19.8	10.0

Work description / Error item	Total	Operations 1 Plant start-up operation	2 Plant output and operation monitoring operations	3 Regular testing operations	4 Inspections during abnormalities	5 Plant shut-down operations	6 Auxiliary equipment start-up and shut-down operations	7 Auxiliary equipment regular switch-over operations	8 Trial- run operations	9 Isolation and isolation restoration operations	Maintenance 10 Surveillance inspections	11 Disassembly inspection work	12 Part replacement and repair work
Error modes													
C2 Wrong interpretation of trigger information	2.0	0.0	0.0	0.0	15.4	0.0	2.6	0.0	0.0	2.1	0.0	1.8	0.0
C3 Vagueness of intent of action	2.0	0.0	4.3	12.5	0.0	0.0	0.0	5.9	0.0	0.0	25.0	1.8	0.0
C4 Substitution with familiar action	3.8	0.0	0.0	12.5	7.7	0.0	2.6	0.0	50.0^{++}	5.6	12.5	1.2	0.0
C5 Difference between internal maps and the outside world	20.9	33.3	19.1	0.0	23.1	0.0	25.6	23.5	0.0	31.9^{++}	37.5	21.0	10.0
C6 Careless operation	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Errors based on rules													
D1 Simplification	12.6	11.1	10.6	6.2	7.7	0.0	10.3	0.0	25.0	11.8	0.0	15.0	0.0
D2 Wrong interpretation of input information	11.2	11.1	7.4	12.5	0.0	0.0	0.0-	5.9	0.0	5.6-	0.0	18.0	40.0^{++}

D3 Simplification of rules	1.8	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	1.2	10.0
D4 Incorrect selection	4.6	11.1	10.6	0.0	23.1	0.0	2.6	11.8	0.0	2.1	0.0	2.4	0.0
D5 Incorrect recollection of information in memory	0.8	0.0	0.0	6.2	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.6	0.0
D6 Forgetting isolated items	1.5	0.0	1.1	0.0	0.0	0.0	7.7	0.0	0.0	0.7	0.0	2.4	0.0
Errors based on knowledge													
E1 Overlooking habitual patterns	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0
E2 Incorrect selection of input information	3.8	0.0	7.4	6.2	0.0	0.0	5.1	0.0	0.0	3.5	0.0	2.4	0.0
E3 Substitution of memory for information that should have been input	11.3	22.2	7.4	12.5	7.7	0.0	5.1	11.8	0.0	19.4	12.5	10.8	20.0
E4 Error in reasoning related to judgment	1.8	0.0	0.0	6.2	0.0	0.0	2.6	0.0	0.0	0.7	0.0	2.4	10.0
E5 Error in reasoning related to decision-making	1.0	0.0	0.0	0.0	7.7	0.0	0.0	0.0	0.0	2.1	12.5	0.6	0.0
Number of samples	716	9	94	16	13	2	39	17	4	144	8	167	10
(%)	100.	1.3	13.1	2.2	1.8	0.3	5.4	2.4	0.6	20.1	1.1	23.3	1.4

Note. Aggregation according to error mode and mechanism and work description (+ +, - p<.01 , +,−p<.05, [a], p<.10).

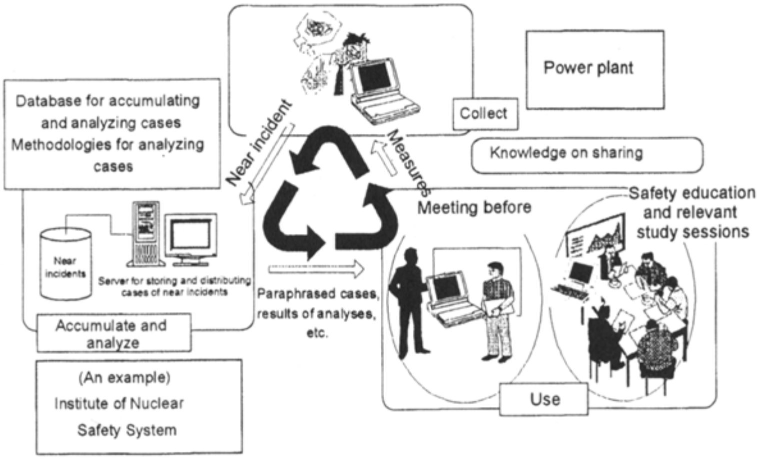

Figure 18.3 A cycle of utilization of near incidents.

To conquer these practices, it is necessary to change the method of collecting information on near incidents in such a way that operators who have experienced near incidents directly report them to a third-party institution so that the reporters are not identifiable. The collected information on near incidents should then be paraphrased and provided as feedback to the actual work sites, thus becoming common knowledge shared by all the operators concerned. In the actual work sites, too, the identification of operators who have reported near incidents should be made impossible. Furthermore, useful information, such as information showing characteristics of near incidents, needs to be given as feedback, by categorizing collected cases of near incidents and making a statistical analysis of them. One example of such analysis is the aggregation and correlational analyses made by Shinohara, Kotani, and Tsukada (1998) of "error mode and error mechanism item" x "work description item," "human error item" x "work description item," and "error mode and error mechanism item" x "human error item." In response to this feedback, each work site should adopt necessary measures as well as share with all operators as common knowledge both useful information and the near incidents experienced by individual operators. Table 18.3 shows the results of Shinohara, Kotani, and Tsukada's aggregation and correlational analyses, and Figure 18.3 presents our conception of a cycle of utilization of near-incident cases.

Moreover, all operators should share a common understanding and knowledge not only of near incidents but also of incidents that actually happened, including hazards and human errors. By systematizing these processes and accumulating data to cover a full range of dangerous spots and operational processes in which operators are prone to errors, it is possible to establish an organization in which near incidents or errors are unlikely to occur.

SHARING KNOWLEDGE ON MEASURES TO CALL ATTENTION

In order to make the occurrence of human errors and incidents unlikely, one requirement, together with sharing knowledge of cases of incidents and near incidents, is to share knowledge on measures to call the operator's attention to the prevention of errors by encouraging himself and others to increase their attentiveness, orient it in the correct direction, and maintain it in the manner shown in Figure 18.1.

Even if an organization succeeds in reaching an agreement on the basic concept of safety and in having every organizational member share knowledge of cases of incidents and near incidents, the organization will not be free of human errors. For human nature is such that its attentiveness does not suffice for the situation it creates. The filter model of attentiveness (Broadbent, 1958) and the distribution model of the resources called attentiveness (Kahneman, 1973) may explain this phenomenon. It is also well known that the level of consciousness decreases as time passes (Hashimoto, 1984) and that if humans continue to engage in an operation, the risks of errors gradually increase.

Various measures have been adopted to call operators' attention during the operation of power plants, from warnings such as "Danger Overhead"; to notices of "advice on a single point," which impart the lessons learned from previous errors; to meetings before the start of work. The measures currently adopted, however, have not proved to be as effective as expected, either because they have become stereotyped or because, with insufficient reasons to support the measures, they have no clear sense of purpose.

To make the measures effective, it is necessary to utilize them only after giving consideration to what effect the measure aims at, how and in what situation the measure should be taken, with what mechanism of attentiveness the measure takes effect, and so on. There have, however, been almost no cases in which the effectiveness of measures was examined thoroughly and systematically in view of two aspects: actual situations when the measure may be used and the principles of the measure. Therefore, in recognition of the importance of systematizing these measures from the viewpoint of error prevention, the Institute of Nuclear Safety Systems has engaged in a study of effective measures to call attention at power plants in order to provide reasons for supporting each measure and to develop systematic ways to effectively utilize these measures (Tsukada & Nakamura, 1999).

We at the Institute of Nuclear Safety Systems first considered how know-how of the measures, which we acquired through our study, should be shared with all the members involved in the operation of power plants. Drawing on the results of our study, we then developed three kinds of materials for the leaders at actual work sites, namely, a reading that provides a clear explanation of know-how of the measures; catalogues that present tools, with the focus on newly developed ones; and a database that covers systematized measures.

Entitled "You Cannot Eliminate Accidents by Simply Repeating 'Let's Be Attentive'—33 Effective Ways to Call Attention," the reading describes the situations that require attention in chapter 1. It then gives a clear explanation of the mechanism of attentiveness in chapter 2, explains typical measures that may be useful on the actual work sites in chapter 3, presents examples of how to utilize the measures according to operations characteristics in chapter 4, and emphasizes that "you should play the main part" in further pursuing safety in the concluding chapter.

The catalogue, "Novel Tools for Calling Attention: Use Every Possible Means for Operators to Remain Attentive," presents 32 tools, with a focus on newly developed ones. The tools are categorized according to their uses, such as "preventing careless mistakes" and "a tool to be used after 2 p.m." The catalogue also provides outlines of the tools, uses, instructions, photographs and illustrations that show how to use the tools, and, for reference, their prices.

The database contains about 100 newly developed measures that are used at power plants and in other industries, and all of these measures are classified based on seven aspects, including purposes of the measures, situations that require calling attention, the directions aimed at by the measures, and the timing for taking measures. When an individual wants to know which measure is most effective in a particular case, he or she can promptly retrieve appropriate measures from the database together with reasons given, based on the findings of psychology and ergonomics, for why the measures are effective. The database also includes model patterns of applying the measures, which were developed for five different operations that are typical of power plants and that have different characteristics (e.g., operations dealing with heavy objects and work involving repeated actions). These model patterns are intended to present optimum measures for each work item from start to finish according to the particular duty. On the assumption that it would be used on the network (Intranet), the database has been established with Hypertext Markup Language (HTML), the language of the World Wide Web, and Practical Extraction and Report Language (PERL), a character-string handling script that is widely used in the Internet.

If know-how of measures is utilized equally at every work site with the help of these three items, it can be expected that operators will come to share a common understanding of safety. At the same time, we also expect that individual operators may want to share their own opinions on know-how, such as "I do it this way in such a situation" and "I have a better way of

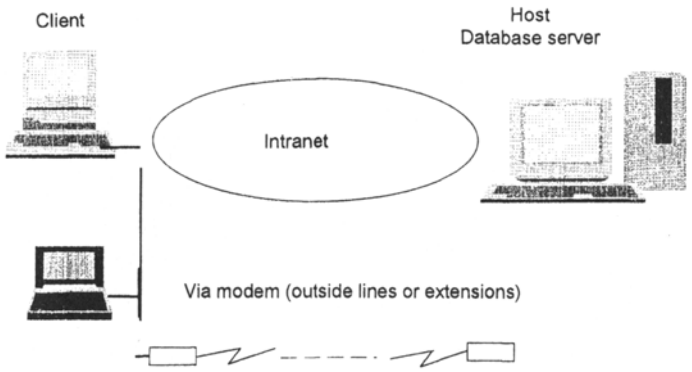

Figure 18.4 Conception of utilization of interactive database system.

dealing with this situation." The database is therefore equipped with a registration function that allows users to enter their opinions.

EFFORTS TO SHARE KNOWLEDGE OF HUMAN ERROR PREVENTION

We have discussed how important it is to share with all organizational members the organization's basic concept of safety, knowledge of cases of incidents and near incidents, and measures to call attention to prevent human errors. Of course, it is important to acquire as much knowledge of human error prevention as possible, but it may also be necessary to collect the vast know-how that individual operators have and share this know-how with the members as part of the knowledge assets of the organization.

In order to share know-how with all the members in this way, it is necessary to carry out activities, open to all members, in which anyone can express their opinions and engage in discussion in order to arrive at a common understanding. User-friendly systems are necessary to enable all operators involved in actual work to have access to the database from their personal computers; operators can thereby retrieve information as well as register their opinions or know-how. Internet technology is now so sophisticated that these systems can be relatively easily established beyond one site to connect several power plants or business offices.

The Institute of Nuclear Safety Systems is now proceeding with the development of interactive database systems that will enable the giving and receiving of knowledge and opinions through the Intranet (see Figure 18.4). These systems should help establish a framework for power plants in which knowledge on human error prevention is shared and errors are unlikely to occur.

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CHAPTER NINETEEN
A Sign System for Safety in Nuclear Power Plants

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Appropriate signage helps workers in nuclear power plants understand their workplace environment. We researched and developed a sign system, that is, a system of indications using various visual communication capabilities specific to characters, colors, and shapes, in an attempt to accurately provide distinctions, guidance, and directive signs that are relevant to the nuclear power plant environment. Our study revealed that effective designs and locations for sign presentations that are based on the viewer's needs, among them layout signboards, direction indication displays, and room name signs, were effective in enhancing understanding of the workplace environment in nuclear power plants. Conformability, redundancy, and consistency were found to be important principles for developing a sign system that contributes to safety in nuclear power plants.

In recent years, efforts have been made in public areas and work environments to direct users so that they know which way to go. For example, destination guides with maps and color-coded indications are provided not only at public places, such as stations, airports, hospitals, and underground malls, but also in office buildings. But these directive signs are not necessarily satisfactory to users. It still often happens that a user cannot find the sign needed when at a loss for which way to go or that the sign at last found is confusing.

Nuclear power plants are not an exception; rather, the issue of the placement of signs has been addressed more slowly in nuclear power plants than in public places. When we began our consideration of signs to provide direction in nuclear power plants, only the minimum number of necessary signs, such as pointers to fireplugs and emergency exits and room name signs, were already introduced; there were few signs providing information on how to find one's current location or a particular destination. Workers in nuclear power plants have had to accept such inconvenient environments.

Appropriate directive signs are thought to improve workers' perceptions of their work space; the provision of such signs is an important measure both to decrease human errors and loss of time when workers move within the workplace and to remove workers' anxiety. Hence, it is essential to establish a sign system in nuclear power plants that is suited to the environment and that is highly discernible, noticeable, and intelligible.

A sign system is a system that provides proper identification, guidance, directions, and so forth through using the visual communication functions of characters, letters, colors, and shapes. Basically, it comprises maps of the premises, floor layout signboards, direction indication signs, room name signs, emergency exit signs, and so on.

Refueling and inspections are regularly carried out in nuclear power plants. A sizeable number of workers is engaged in such activities so that the activities can be finished in as short a time as possible. Many of the workers are strangers to the interior of the nuclear power plant. In addition, even regular operators, who should be familiar with the plant, have caused some troubles in recent years. In one case, an operator who should have operated a valve in a unit in outage mistakenly went to another unit in service and operated the valve there. As a result, a power generation disorder occurred.

In a nuclear power plant, especially in radiation control areas, each piece of equipment is set in a concrete-walled room for radiation protection; this room is an enclosed space without any windows. The space is visually shut off from the world outside, and the design of the nuclear power plant buildings makes it difficult to acquire a sense of direction.

One Japanese nuclear power plant conducted a survey of on-site workers; according to it, about 80% of workers said it was difficult to find their way when they first started to work there. Though workers reported that they are now more accustomed to the environment, over 40% still found passages there unintelligible. Less than 5% said that these passages are intelligible. About 70% of respondents cited radiation control areas as especially difficult areas to find one's way. And over 50% said they want floor layout signboards and room name signs within radiation control areas. The facilities for which they wanted signs are extinguishers, emergency exits, paging areas, staircases, and gateways (Fukui, Natori, Akagi, and Sakurai, 1998).

Just like public places, nuclear power plants need sign systems. Even well-trained people can make errors. To ensure safety in nuclear power plants, one should provide an environment where a user can be sure of where he or she is. A sign system is considered to be an effective measure for accomplishing this goal.

PRINCIPLES FOR A SIGN SYSTEM

A sign system serves various purposes. For the purposes of providing guidance and directions, one should use layout signboards, direction indication signs, and room name signs. For example, an ideal situation is when one can see in a layout signboard one's location in relation to the destination, then make sure through a direction indication sign that one is moving in the correct direction, and finally learn through a room (facility) name sign that one has reached the desired destination. We advocate three principles for making the functions of a sign system effective for users: conformability, redundancy, and consistency.

By "conformability" we mean conformability between users' tendencies in perceiving space and the manner in which locations in a particular space are indicated. For example, if one takes one's current location in a layout signboard as a starting point, one tends to perceive points above it as indicating points ahead of one and points below it as indicating points behind one. To prevent misperception of directions, a sign system that conforms to such human tendencies in perceiving directions should be used.

By "redundancy" we mean redundancy of the information to be signified. The information contained in signs can be provided in the form of pictograms, letters, colors, and shapes. Repetition of the same information in different forms prevents people from overlooking the information indicated.

Finally, "consistency" refers to consistency in the methods used for indication. For example, the means of indicating information in signs should be standardized across nuclear power plants. If these means are different from site to site, users may become confused and misunderstand the information provided. Therefore, in the interests of workers who move between nuclear power plants, the means of indication should be consistent.

In the following sections we explain some cases that we have considered in light of these three principles.

CONFORMABILITY

Conformability between users' tendencies in spatial perception and the manner in which locations and directions are indicated can be illustrated through another example: Taking one's current location in a layout drawing as the starting point, one tends to perceive up as ahead, down as behind, right as to the right, and left as to the left. To prevent misperception of directions, a site should have an indication system that conforms to such human tendencies in perceiving direction. Misunderstandings may arise if the meaning of displays can only be understood through careful consideration. Signs that can be intuitively understood at first sight conform to human tendencies in perceiving direction.

We shall now show how buildings are laid out in a nuclear power plant. Figure 19.1 provides a simple schematic drawing of a plant. In this figure, circles represent reactor containment vessels. Located between them are, from top to bottom, an auxiliary building, an intermediate building, and a turbine building.

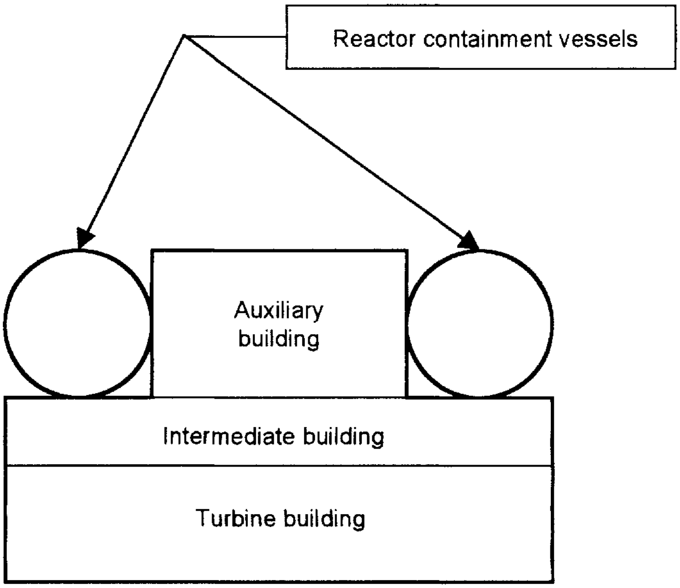

Figure 19.1 Schematic drawing of a nuclear power plant

Below we explain what we discussed with nuclear power plant workers with regard to examples of conformability between layout signboards and spatial perception tendencies. Directions in layout signboards can be shown in either a fixed or a flexible way. The picture in the upper left corner of Figure 19.2 shows various positional relations between a person and a layout signboard in a nuclear power plant. Suppose Persons A, B, C, and D are facing different ways and see Panels A, B, C, and D, respectively. With fixed-direction layout signboards (the picture in the upper right corner of Figure 19.2), directions (up, down, right, and left) are unified and fixed, regardless of which way a person is facing. Reactor containment vessels are always indicated at the top of the signboard, just as in maps the direction north always points upward. With flexible-direction layout signboards (the lower row of pictures in Figure 19.2), however, the directions (up, down, right, and left) in the signboards are dependent on which direction the user is facing. For example, in the picture in the upper left corner of Figure 19.2, Person B is facing to the right, and a reactor containment vessel is located to the left of him. Therefore, in the flexible-direction layout signboard he would see, the reactor containment vessel is shown to the left. The same thing can be said of the layout signboards that Persons A, C, and D would see.

Thus, in flexible-direction layout signboards, reactor containment vessels may be shown to the right or the left. Many older workers, accustomed to seeing signboards with containment vessels toward the top, are in favor of the fixed-type signboards. But there is a problem with this fixed orientation.

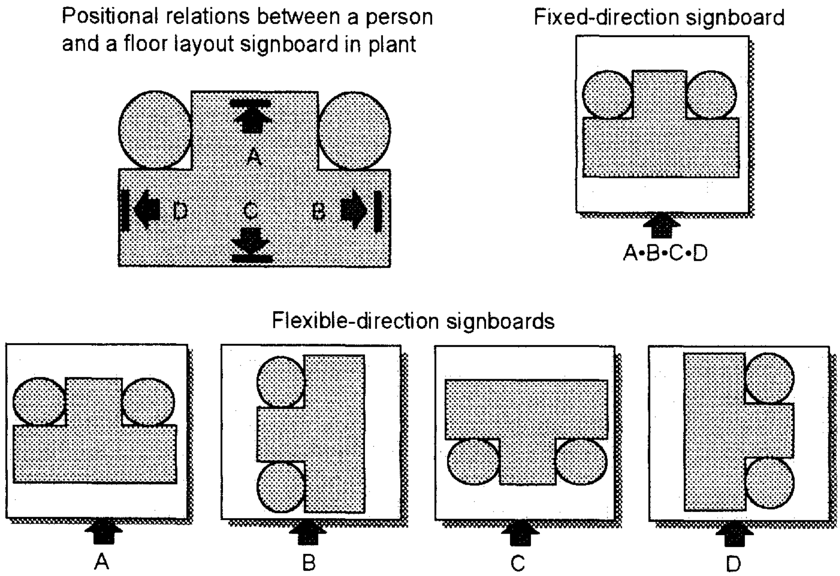

Figure 19.2 Floor layout signboards facing different directions

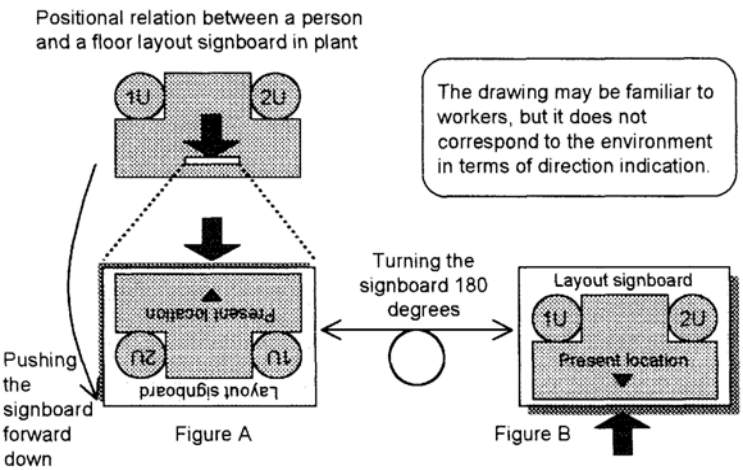

Figure 19.3 A fixed-direction layout signboard. 1U=Unit 1; 2U=Unit 2.

For example, suppose that the picture in the upper left corner of Figure 19.3 is a real nuclear power plant and that a person stands there, facing the turbine building (the picture shows him facing downward) and looking at a fixed-direction layout signboard. Picture A is what results from pushing the top of the signboard down, and Picture B is what one obtains by turning Picture A 180 degrees, so that one can see it easily. Picture B is what the person in the

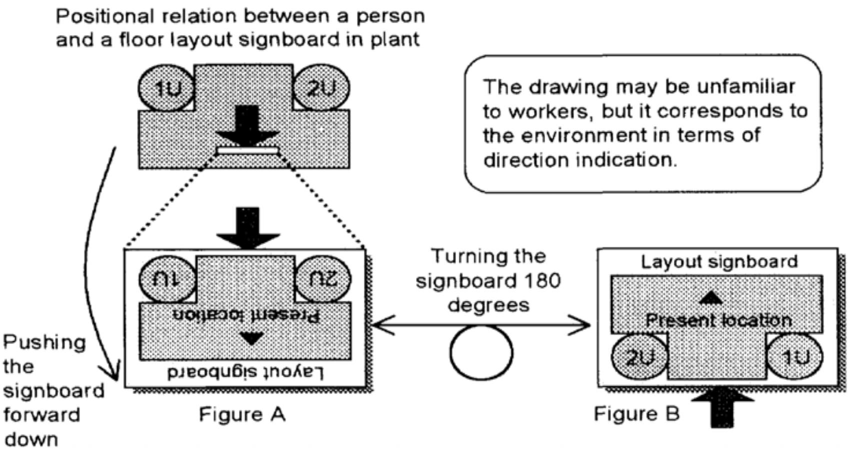

Figure 19.4 A flexible direction layout signboard. 1U=Unit 1; 2U=Unit 2.

plant does see. People accustomed to seeing this type of drawing would not find anything strange with this particular signboard. But when one compares Picture A (the picture before it is turned 180 degrees) with the real plant in order to see positional relations between the plant and the signboard, one sees that the first unit and the second unit are located in reverse. In addition, the front and the back of the building are in reverse, too, for when looking at a layout signboard, one perceives points above the present location as ahead of oneself and points below it as behind oneself. In this way, fixed-direction layout signboards may not conform to the directions that the user perceives in the environment. They therefore are not suitable for providing information on how to reach a destination.

A flexible-direction layout signboard is illustrated in Figure 19.4. Pictures A and B in this figure are what one obtains through the same manipulations that were carried out for Pictures A and B in Figure 19.3. The signboard that the person in the plant sees shows the reactor containment vessels at the bottom of the picture, so people accustomed to seeing drawings with containment vessels at the top would feel somewhat uncomfortable with this signboard. But when one compares Picture A with the real plant, one sees that the picture exactly corresponds to the real plant in terms of positional relations, that is, ahead, behind, right, and left. In addition, Picture A entirely conforms to the perception of directions. Hence, the flexible type is more suitable for directive signs than the fixed type.

A simpler example follows. World maps show the North Pole at the top and the South Pole at the bottom. If one turns a map around to reverse top and bottom, one gets an unfamiliar world. This strangeness comes from the difference between the resultant map and the one to which one is accustomed, that is, the perceived map. Then, if one pins the world map on a southern wall with the North Pole at the top and points in the direction of a neighboring country, one sees that the direction of the country in the map is opposite its actual direction. Thus, layout signboards that conform to people's perception of directions are required to show users how to reach their destinations, rather than those to which we are accustomed.

REDUNDANCY

As mentioned earlier, redundancy in a sign system means using signs that have the same meaning but different forms of signification, such as pictograms, letters, colors, and shapes, in order to prevent people from overlooking or misunderstanding the indicated information. Redundancy is also achieved through repeatedly displaying signs with the same meaning. We shall now explain some cases we have considered in light of redundancy.

Figure 19.5 shows various signs we have considered. In relation to redundancy of floor layout signboards, we have considered displaying a layout drawing of the whole plant and a magnified layout drawing of part of it together in the same panel to help users understand their current location. We also have placed arrows pointing to the current location not only in the magnified drawing of part of the plant but also in the layout drawing of the whole plant. In addition, we have used pictograms for general facilities, such as emergency exits, fireplugs, and paging areas, in order to indicate information efficiently. Finally, we have affixed words to the pictograms in order to prevent users from overlooking or misunderstanding the signs. We have attempted to ensure that wherever one is in a building, one finds at least one sign with the floor layout. It would be inconvenient if users had to go up and down looking for a floor layout sign when they are at a loss for where to go.

The means of indicating direction include hanging signs, signs fixed on the wall, and signs on the floor; each of these means has its own characteristics. Generally speaking, hanging signs and signs on the wall are easily noticed from far away, whereas signs on the floor are not. Signs fixed to the floor can, however, indicate all directions in an intuitively understandable way, whether ahead, back, right, or left. Hanging signs indicate right and left quite intelligibly, for they face walking persons, but this type of sign cannot indicate directions parallel to the user's walking direction (ahead or back) in an intelligible way. It is therefore important to combine a hanging sign, a sign fixed on the wall, and a floor sign, rather than use only one way to indicate direction; this strategy of combining signs compensates for the defects of each sign type and provides redundancy.

Room name signs are illustrated in Figure 19.6. For designating room names, hanging signs are more noticeable than signs fixed to walls, because signs on the wall, often set parallel to the user's walking direction, cannot be seen until the user draws near, whereas signs that hang perpendicular to the user's walking direction can easily be seen from far away. But signs fixed to the wall have the merit of pointing unambiguously to the place designated. Signs that project from the wall are a possible way to combine the merits of both hanging signs and signs on the wall. Therefore, for the designation of room names, too, it is important to combine a hanging sign, a sign on the wall, and a projecting sign in order to compensate for the defects of each sign type and provide redundancy.

In addition, we also affixed words to some pictograms for directions and room names, in order to prevent users from overlooking or misunderstanding a sign.

When people look at a floor layout signboard, they first look for their current location and then look for which direction their destination is. But if they are not sure of how directions in the sign correspond to the actual floor site, that is, up, down, left, and right, they cannot discern which direction they should go. For this reason, direction indication signs are set near floor layout signboards. In comparing these two kinds of signs with each other, people learn what the directions up, down, left, and right indicate in the drawings and see which way they should go. A direction indication sign near a floor layout signboard may look superfluous, but such redundancy is important for assuring people of directions in the layout signboard.

In the Kansai Electric Power Company nuclear power plants, Units 1, 2, 3, and 4 are identified with colors: white, yellow, blue, and pink, respectively. Equipment, doors, walls, and floors are painted in their respective unit colors. In addition, unit numbers are indicated in big letters. Unit colors and numbers are seen in a wide range of places, including inside walls of buildings and equipment as well as various facilities on the premises. Wherever a person is, he or she can see to which unit the equipment belongs. These measures provide a good example of redundancy of signs.

CONSISTENCY

Sign systems should not be established in different ways from site to site but rather should be unified according to a common standard. If the means of indication in signs are different from site to site or from building to building, users may become confused and misunderstand the information indicated. Therefore, because workers move between nuclear power plants, consistency in the forms of signification in signs should be addressed.

Pictograms are visual symbols; they depend not upon letters but upon designs. A pictogram has the merit of making people who speak different languages think of the same object that it is intended to convey. But misunderstandings arise if different pictograms are used for the same object or if the same pictogram is used for different objects.

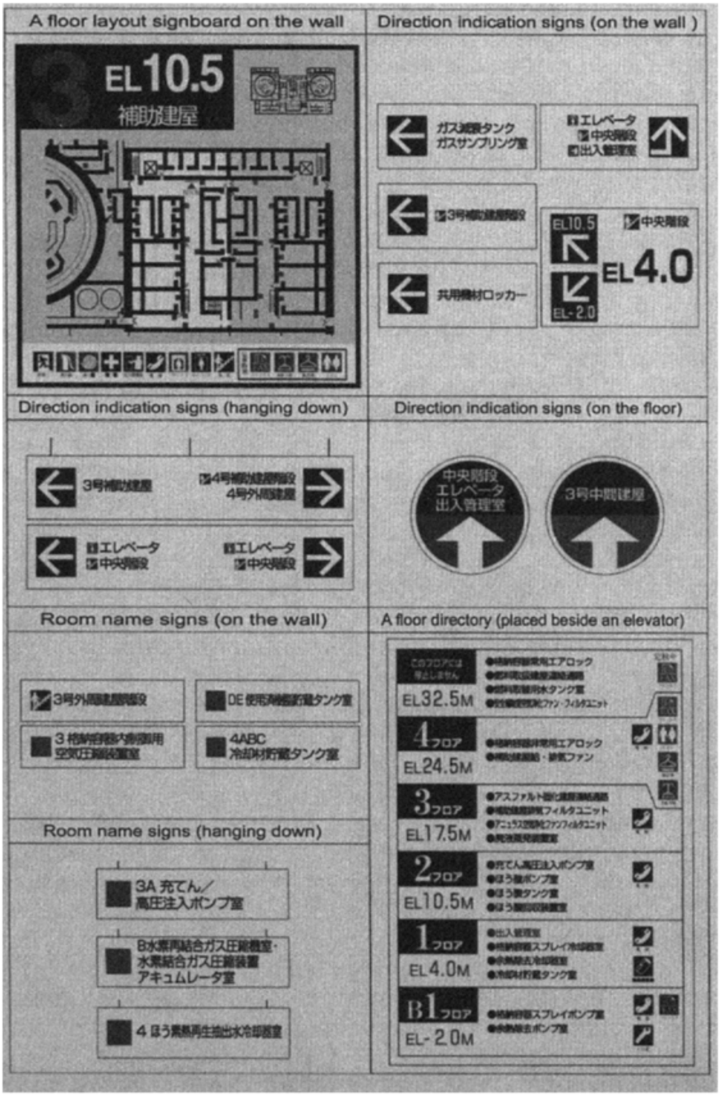

Figure 19.5 Draft sign designs temporarily placed.

Pictograms intended to provide assistance in finding one's way in public places are internationally standardized by the International Organization for Standardization (Murakoshi, 1987). But there are still no standard pictograms for facilities often used by workers in nuclear power plants, such as the room for controlling access to radiation control areas, reactor containment vessels, and airlocks, which are specific to nuclear power plants. This lack of standardization means that it is possible that different pictograms are used

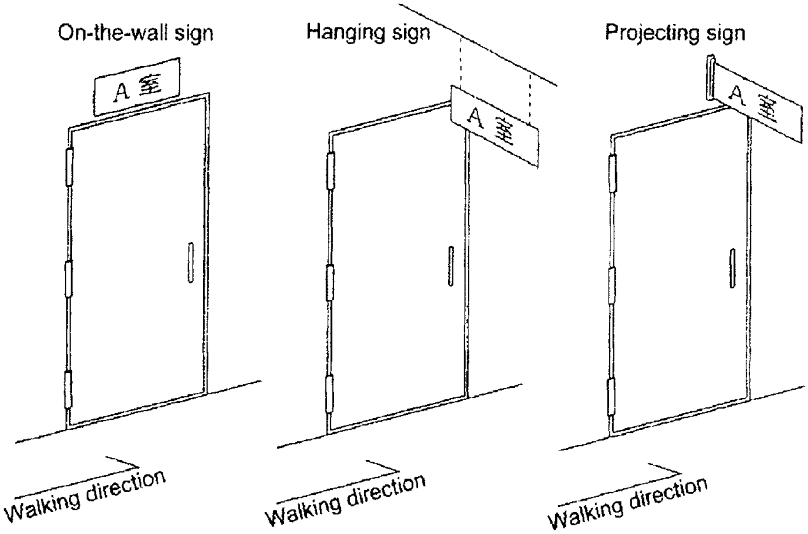

Figure 19.6 Room name signs.

from plant to plant, thereby causing confusion. Sign systems should be standardized in the nuclear industry, too, so that consistency between nuclear power plants can be established.

IMPORTANT POINTS FOR SIGN SYSTEM PLANNING

The basic attitude of the sign system planner has a great influence on the system's serviceability. One point that the planner should keep in mind when designing a system is to give priority to intelligibility. The sign system planner should try not just to design signs that he or she finds attractive but also to place main emphasis on creating an intelligible environment for the workers at the site.

A second point is to pay attention to existing visual environments. In placing signs in an environment, the planner should try to make them visible and intelligible. Existing plants already have backgrounds against which to place signs, so it is important to keep in mind what colors make up the present environment and design signs that can most optimally be set against such background colors.

A third point is to reflect the opinions of on-site workers in the planning. It is important to take workers' opinions into consideration when planning a sign system so that it can be made intelligible for workers. If possible, the planner should conduct polls or interviews in advance with the users.

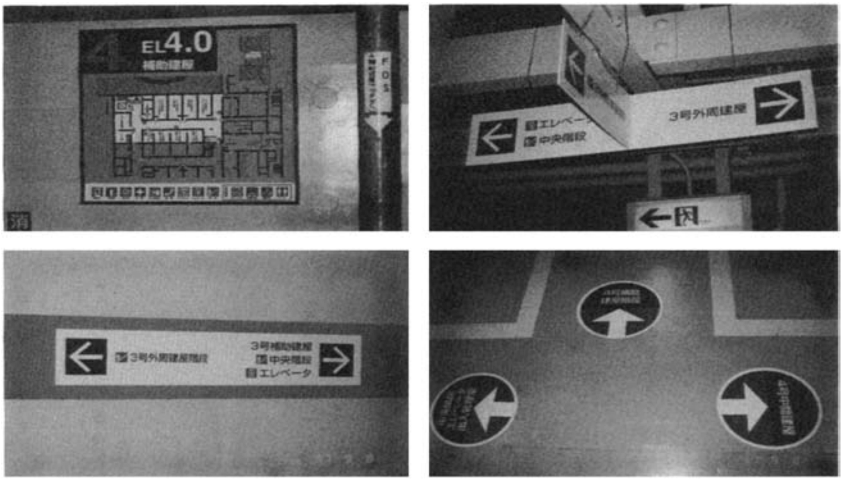

Figure 19.7 Temporary placement of signs on the site.

What we found through polls and interviews is that on-site workers call buildings and facilities more often by their abbreviated names than their formal names. Hence, if only formal names are shown in layout signboards and direction indication signs, workers may not understand these unfamiliar names. For example, at the work site, auxiliary buildings are referred to as A/B and intermediate buildings are referred to as I/B. When creating a sign system, the planner should pay attention to the names that users usually use. It is difficult to realize how important this step is if the planner only considers a system from his or her desk.

In order to put these three points into practice, we carried out research for a sign system by using the following steps: investigation of the current sign system and visual environment in nuclear power plants; a poll of workers on unintelligible places and various needed directive aids; a presentation of draft guidance indication designs, and discussion with employees on the utility of these designs; temporary placement of directive signs on the site (see Figure 19.7); and polls and interviews with workers about the temporarily placed directive signs. Through this process of investigation and consideration, we have been able to propose an effective sign system for nuclear power plants.

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