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Naosuke Itoigawa, Bernhard Wilpert and Babette Fahlbruch

Emerging Demands for the Safety of Nuclear Power Operations

Challenge and Response

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PREFACE

This volume is the third publication to develop from an extremely fruitful, longstanding, and international cooperation between two research institutions: the Institute of Social Research within the Institute of Nuclear Safety System, Inc. (INSS/ISR) in Mihama, Japan, and the Research Center Systems Safety (Forschungsstelle Systemsicherheit—FSS) of the Berlin University of Technology, Germany, within the Institute of Psychology and Ergonomics. Metaphorically, two different strands of research joined here in marriage more than ten years ago. The INSS/ISR, being linked to the Japanese Kansai Power Corporation, has first and foremost the mission to address topics of immediate practical safety relevance in the nuclear industry. The FSS, as a university research unit, has the mission to combine basic safety-related research with practical approaches to safety in high-hazard industries.

To extend this metaphor, so far four children have been brought to life from this marriage. Both institutions sponsored the First International Conference on Human Factor Research in Nuclear Power Operations (ICNPO I) from October 31 to November 2, 1994, in Berlin. The intention of this conference was to take stock of industry and disciplinary issues, bringing together some forty internationally known social scientists engaged in human factor research in the nuclear industry. The success of this conference encouraged the marital partners to conduct jointly ICNPO II, again in Berlin, from November 28– 30, 1996. This conference focused on more specific issues, such as the nuclear industry environment; organizational, group, and individual aspects of nuclear safety; and feedback from experience (see J.Misumi, B.Wilpert, & R.Miller, eds., 1999, *Nuclear Safety—A Human Factors Perspective* [London: Taylor & Francis]). The positive response of the academic community was such that ICNPO III was planned and held from September 8– 10, 1999, in Mihama, Japan, with a focus on safety culture (see B.Wilpert & N.Itoigawa, eds., 2001, *Safety Culture in Nuclear Power Operations* [London/New York: Taylor & Francis]).

ICNPO IV, again held in Mihama, Japan, from September 9–11, 2002, gave birth to this third publication, the fourth child from the fertile joint activities of INSS/ISR and FSS. This volume addresses the recent emergent challenges to and possible solutions from the nuclear industry. These challenges arise from trends and conditions such as the new economic environment of energy production as a consequence of global competition, new regulatory strategies, new technologies, and new attitudes among the public. They all require new managerial responses and adjustments, which in turn call for new analytic tools and methods to gauge the situation and react appropriately. The aim of this volume is to contribute to further increased nuclear safety levels, which, in inter-industrial comparison, may be judged to be already on a comparatively high level.

Mikio Kitada
President
Institute of Nuclear Safety System, Inc.
Mihama, January 2004

Professor Kurt Kutzler
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Ginger A.Diekmann has served as copy-editor for this volume. We gratefully acknowledge her precision and superior professional performance. Similarly, Matthias Welker edited the different figures in the contributions to this volume, an often difficult and strenuous task which he conducted with great skill and tenacity. We acknowledge his contribution gratefully as we acknowledge Ulrike Wiedensohler's crucial and patient service as a go-between to editors and contributors and her outstanding achievement in finishing the lay-out of the volume in due time. 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 2004

INTRODUCTION

NAOSUKE ITOIGAWA AND BERNHARD WILPERT

Nuclear Industry in a New Environment

While the inherent challenges posed by the need to ensure safe operations and the containment of radioactive materials have been a necessary accompaniment in the nuclear industry from its very beginnings, we now seem to be entering a new era of further emerging challenges and demands confronting this industry. These challenges are mainly due to recent changes in the circumstances of the energy-producing industry. To mention a few of these changes, worldwide we note measures to deregulate energy markets, with a resultant increase in international merger activities and an intensification of competitiveness among utility operations. Tighter competition forces cost-saving strategies, such as reducing qualified operative personnel and outsourcing certain functions that previously were operated and controlled inside plants or companies. These measures contribute to a loss of knowledge and competencies within nuclear operations, which is further propelled by the natural aging and attrition of nuclear operations staff, often originally hired during the heyday of nuclear energy production, which now into the beginning of the twenty-first century was some thirty or forty years ago. Furthermore, we note a relative lack of higher education institutions that train sufficient numbers of persons and equip them with the knowledge needed to run nuclear plants efficiently. The natural aging of originally implemented technical components is often responded to by replacing them with new technologies, a trend often necessitated by the disappearance of manufacturers of original components. Decades of conscientious technical back-fitting of nuclear installations makes it now very cost-intensive to expect additional safety gains through investments in technical improvements. Hence, investments in the human dimension of nuclear operations become an important target and opportunity (catchword “safety culture”). However, this new and unavoidable preoccupation with the “human factor” is likewise a challenge for an industry that, through tradition and the nature of its tasks, always seems to be an exclusive domain of engineers. Finally, the age reached by some nuclear installations now makes it mandatory to address the absolutely novel issues surrounding technical and human factors when decommissioning nuclear installations, along with the concomitant public reaction concerned with the Achilles’ heel of the nuclear industry: ultimate storage of its waste.

Given the diversity of new challenges, it is no surprise that the industry finds itself amid valiant efforts to search for an adequate response. All around the world the nuclear industry has intensified its contacts with research and educational institutions that offer possibilities of interdisciplinary cooperation and joint efforts in facing these challenges. One direction of these efforts is geared toward better understanding the nature of new challenges, that is, it addresses the development of diagnostic instruments. With the results from improved and more appropriate diagnostic tools as its basis, the pursuit of adequate defensive measures will be the next step. At the same time the nuclear industry’s concern for its public image will always remain a critical topic for its long-term perspectives. With the aim of making some contribution to the discourse on emergent challenges for the nuclear industry, the present volume gives in four parts exemplary evidence for four salient aspects of the nuclear industry today: (a) new challenges, (b) the problems and efforts in developing new investigative instruments, (c) examples of some reactions of the industry to new challenges, and (d) the role of public attitudes toward the nuclear industry.

PART ONE

Emerging Challenges

INTRODUCTION

The three chapters of Part One somehow set the panorama for the present volume. Frischknecht's contribution addresses the epochal shift from the traditional exclusive concern with technical barriers for nuclear safety toward human factors: the inclusion of individual, organizational aspects, managerial safety-oriented management actions, and regulatory stipulations toward safety management systems. Thus, he covers a wide gamut of newly requisite non-technical contributions to nuclear safety from his Swiss regulatory perspective. In its integrative and interdisciplinary orientation the chapter in itself presents a conceptual and practical challenge by calling for a new systemic thinking about nuclear safety.

Chapter 2 by Wahlström reports first results from an international comparative study of European managers' perceptions of emergent challenges for the safe management and operation of nuclear power plants. The focus of this international study ("LearnSafe"), which is supported by the Commission of the European Union, aims to identify possibilities of learning from best practices. The preliminary results reported in this chapter elaborate the diverse challenges mentioned in the general introduction to the structure of this volume.

Chapter 3 by Baram demonstrates convincingly that the decommissioning phase of a nuclear power plant presents a large variety of challenges which go far beyond only technical safety considerations. It is a large scale, complex, lengthy managerial and regulatory task which comprises the cooperation of a multitude of national and local actors and implies a large variety of psychological, legal, economic, and political aspects. Baram, therefore, draws heavily on the holistic notion of safety culture in order to shed light onto a new emerging responsibility of nuclear industry.

CHAPTER 1
A CHANGING WORLD: CHALLENGES TO NUCLEAR OPERATORS AND REGULATORS

Albert Frischknecht

In their efforts to ensure that the population and the environment are not exposed to harm through radioactivity, nuclear operators and regulators have focused on the reliability of engineered barriers. During the last decade the focus has changed from the technical aspects of barriers to those processes that maintain the reliability of barriers. Thus, the performance of individuals and organizations is viewed as a major contributor to nuclear safety. However, the regulation of human and organizational aspects is difficult because, unlike the technical side of nuclear safety, there are no specific requirements. Moreover, changes in the political, social, and economic environment can have a considerable influence on individuals and organizations. These influences must be anticipated and controlled through the use of dedicated concepts and instruments, designed by experts in the social sciences. Recent developments appear to have split the world of nuclear power into two disciplines: technical specialists and specialists in the area of human and organizational factors. In this chapter we discuss the history of these developments and the concept of the "organizational event." We then discuss an approach used in Switzerland, which may offer some solutions through its integrated, interdisciplinary approach to nuclear safety.

INTRODUCTION

Nuclear power plants (NPPs) are designed to operate for several decades. This period of time usually exceeds the professional life of most individuals, considerably exceeds the duration of usual business plans, and in most cases exceeds by far the term of office of politicians. Technology continues to develop over this period of time, people retire, business goals and plans are rerouted, political programs are modified according to election results, and so on. NPPs and their operating organizations are therefore subjected to a changing array of internal and external factors.

It is the function of NPPs to produce electrical energy in a reliable and safe way, independent of any changes that may occur in the outside world. No harm to the population or the environment should occur over the entire lifetime of an NPP. Since the very beginnings of the nuclear industry, engineers specializing in process and material technology have designed technical features to ensure that nuclear power generation is a safe and reliable process. Operational experience, research results, and technological developments have led to the improvement of concepts, systems, components, and processes. Proven methods and rules have been applied to adapt plant technology to the most recent advances in engineering and scientific knowledge. Rules have been established and documented in plant-internal procedures and plant-external legal and regulatory documents. Nuclear technology may therefore be regarded as a firmly grounded and mature technology.

Despite this strong emphasis placed on safety, several severe incidents and accidents have occurred in the nuclear industry. Interestingly, the two most severe cases, Three Mile Island (1972) and Chernobyl (1986), had their causes not in the technical domain, but in human and organizational factors. With these accidents it became evident that the roles and limitations of humans in these specific settings had not been taken into account properly. Why? The plants were designed by engineers. The technical support of operators—alarms, indications, training, and procedures—was designed and provided by engineers. The organizational issues at the plants were also treated by engineers. New emerging challenges —external factors such as policy, the economy, and society—bring new challenges to the safe operation of NPPs. Thus, the following questions should be posed. Are engineers fit to cope with these issues? What competencies are needed? What can we learn from history?

The example of the Swiss Federal Nuclear Safety Inspectorate (HSK) illustrates a possible approach to coping with these challenges from a regulatory point of view. HSK revised its regulatory guidelines for the organization of NPPs, taking into account recent developments in the areas of safety culture and management of safety as well as state-of-the-art knowledge in the area of organizational development and assessment.

THE ROLE OF HUMANS IN NPPS: THE DEVELOPMENT OF INDUSTRY APPROACHES

From the perspective of human factors, the development of the nuclear industry may be categorized into three areas: technology, ergonomics and human performance, and safety culture.

The technology phase

Nuclear technology began with the first controlled fission process in the “Chicago Pile 1” on December 2, 1942. Led by Enrico Fermi, physicists initiated the first controlled nuclear chain reaction. In the aftermath, it became the task of specialized engineers, the pioneers of nuclear technology, to bring the concept to an industrial level. Technology and technical concepts were used to maintain the nuclear process at the necessary level of reliability and safety. Humans were trained to control the process and to intervene in the event of an emergency. Humans were expected to adapt to the process. Up to this point, humans were not considered part of the system.

The phase of ergonomics and human performance

The accident at the Three Mile Island NPP raised questions about the role of humans in the nuclear process. The mental capacity of humans is reduced under stressful situations.

The ergonomics of the control rooms, therefore, became an important issue. Operator aids, such as safety parameter display systems, were introduced, and the ergonomics of procedures were examined and improved. Moreover, the accident demonstrated that operators’ knowledge about details of the processes has a major influence on the safety level of the plant. The utilities improved their training concepts during the following years, and full-scope simulators started to become important instruments in the training of reactor operators.

Because the nuclear industry was still dominated by engineers, it was engineers who were concerned about the limitations of humans. Their views formed the concepts for improving the safety of the plants. From an engineer's point of view, a facility or device functions well when it runs without unexpected interruptions and failures. As a consequence, the absence of failures was interpreted as an indicator of quality and safety. According to this view, the prevention of technical failures and human errors improves the reliability and safety of NPPs. Therefore, event investigation became an important issue, and sophisticated event analysis concepts and tools were developed, with a special emphasis placed on the analysis of events having a human-failure component. Utilities and regulators regarded the number of a licensee's events as a (non-) safety indicator. In the framework of probabilistic safety assessment, operators were regarded as parts of the system, like components, which either acted correctly or failed. Hence, human reliability analysis was a new discipline for predicting the probability of human errors. The role of humans in the process was recognized, but humans were regarded as the weak elements in the system.

The safety culture phase

The Chernobyl accident revealed that it is not just the performance of individuals that contributes to the safety of NPPs. The influence of the NPP's organization on humans and the resulting attitudes of the individuals were also identified as important factors for safety. The concept of a safety culture was introduced, first as a headline in a meeting shortly after the accident and later in "Basic Safety Principles for Nuclear Power Plants" developed by the International Nuclear Safety Advisory Group (INSAG, 1988) of the International Atomic Energy Agency (IAEA). Although the accident was mainly caused by human actions influenced by organizational constraints, it was still engineers who discussed the Chernobyl accident. Thus, it was engineers who applied the term "safety culture" to the nuclear industry. Engineers wrote a definition of safety culture and described a first attempt for its evaluation (INSAG, 1991). The IAEA took the initiative in further developing the concept of safety culture, which led to an IAEA-run safety service, the Assessment of Safety Culture in Organizations Team (ASCOT), which was later transferred to the ASCOT self-evaluation tool (ASCOT, 1996).

The first conference on safety culture took place in Vienna in 1995 (see American Nuclear Society/ Nuclear Energy Agency, 1995). Many presentations dealt with methods to evaluate safety culture. Some attempted to provide a better definition of the subject, and a few described attempts at the development of a safety culture. It was one of the first nuclear conferences in which a substantial number of the presentations dealt with nontechnical issues.

The reaction of the nuclear industry

The two accidents mentioned above shocked the entire world. The Chernobyl accident clearly demonstrated that a nuclear catastrophe is a real possibility. The world reacted. Politicians, public organizations, regulators, and operators initiated programs for the prevention of another nuclear accident. The international collaboration of operators within the World Association of Nuclear Operators and regulators within the IAEA and the Organisation for Economic Co-operation and Development's Nuclear Energy Agency (NEA) fostered the exchange of information in order to provide opportunities to learn from each other (IAEA/NEA, 1998). It became clear to everyone concerned that another major nuclear accident would mean the end of the nuclear industry. Perhaps this combined effort has contributed to the fact that no major accident has occurred in an NPP in the past 16 years.

The current situation

First, the number of reported incidents per year has not decreased. This result is not surprising, as the sensibility to incidents has increased. Operators have recognized that minor events can be seen as precursors of major incidents. Their deeper analyses have revealed weaknesses that could have remarkable consequences. The systems used for the distribution of information gained through incident analysis have provided the opportunity to learn from others.

Second, the cause of incidents has changed. Formerly, technically induced incidents were in the majority, but now human-induced incidents are on the increase. One reason for this development is improvements in the technical domain. Another reason may be increased openness toward human failures. Concepts such as near-miss reporting, low-level event analysis, blame-free culture, and so forth have helped to create a more open view attitude toward human behavior and to look to human failures as a source of information for making improvements. Hence, the causes of incidents have not changed, but the interest in human factor issues has increased.

Third, a new type of event has emerged. In the 1990s several NPPs in Europe and the United States reported a new type of occurrence that we may call organizational events. Managers of NPPs detected deficiencies in their organization and in management which resulted in technical weaknesses due to work-order backlogs, insufficient coordination during maintenance, and irregularities in daily work. They saw that they could no longer bear the responsibility for the safe operation of their plants as long as these deficiencies were not resolved. This new type of event resulted in the temporary shutdown of several NPPs all over the world. As a result, operators and regulators started to focus increasingly on organizational issues.

The "organizational event"

The "appearance" of organizational events brought new challenges to operators and regulators: The events showed several common similarities:

1. Unlike the "traditional" incidents in NPPs, in organizational events nothing "happened" that required an immediate reaction.
2. In many cases, external influences could be seen as a contributor to the decline in the organizational performance of NPPs. However, it is almost impossible to predict how these external factors may affect an NPP. The correlation between an external factor and a specific safety issue is unknown.
3. In most cases, the reaction of an organization to a changing external factor is rather slow. It takes a long time to detect a change in process, and once it is detected it may already be too late to react in a smooth and controlled fashion.
4. The decline in organizational performance is often not recognized by the members of the organization concerned.
5. Existing quality management programs are not suitable for detecting a gradual deterioration of performance.
6. No legislative or regulatory requirements define an acceptable level of organizational performance. There are no established standards, methods, or tools available to identify, evaluate, and cope with these new issues.
7. Most of the persons involved—members of the safety authority and operators—are technical specialists. They are not very familiar with organizational problems; in other words, it is not part of their daily activities.

8. In order to solve identified problems, operators (and regulators) temporarily consult external specialists. As soon as the problem is resolved, they continue to manage the organization on their own.

To summarize, in most cases the observed decline in performance could not be traced back to a specific cause, but there were many indications that external factors triggered the decline. Most plant managers responsible for detecting, analyzing, and overcoming problems were not specialized in dealing with these issues; they are technical specialists used to dealing with technical problems. A similar situation applies to regulators. They had no tools and no standards for evaluating the plant's performance or for setting requirements on organizational issues.

Approaches for coping with organizational events

In contrast to traditional incidents in NPPs, organizational events do not "happen." Hence, a need to react is not triggered and, therefore, may not be perceived. A tool to cope with this new kind of event must take into account the possibility of a steady decline of organizational performance. A more appropriate tool would be proactive; that is, it would prevent such events well in advance. Both regulators and operators have recognized the "new" problems and the need to deal with these new issues. The ongoing debates in the development of the safety culture concept have sensitized the nuclear community to this new field. The first Technical Committee Meeting on Organizational Factors was organized by the IAEA in 1997 (IAEA, 1997). Other institutions have taken up the subject and searched both for approaches to deal with organizational and safety culture issues and for a way to assess organizational performance (NEA, 2000; Wilpert & Itoigawa, 2001). However, the safety culture concept, as defined up to now, is too diffuse to make it usable for practical applications. As the IAEA document on safety culture points out (INSAG, 1991), safety culture is not tangible.

The nuclear industry has been searching for management rules and procedures, as well as practical tools. The quality management systems of NPPs, already well established, do provide rules and procedures (IAEA, 1996), but are they suitable for dealing with these emerging issues? Today's quality management systems are somewhat "static." Compliance with the rules maintains a predefined standard of quality and reliability. Is this strategy sufficient for safety? Probably not, for safety involves much more. It requires continuous attention and a constant striving for excellence, which in turn requires a different approach: Safety issues that are implicit and somewhat hidden within the quality management system must be made explicit. They require permanent attention and must be managed differently. There is a need for explicit safety management.

SAFETY MANAGEMENT: A NEW TOOL FOR THE UTILITY OPERATOR

The operator is responsible for the safety of the plant and must ensure that the technical processes operate safely and reliably. This requirement may be guaranteed by a competent and motivated crew with adequate procedural and technical means. Quality assurance systems, introduced in all NPPs, are seen as the precondition for stable, safe, and reliable processes. According to this logic, if the NPP staff follow the procedures, the plant is regarded as safe and reliable. Yet this concept does not consider factors such as personal attitudes, motivation, and engagement. Even the best procedure is useless if it is circumvented or not used. People perform the work, not the procedure.

Safety culture was thought to be the binding agent between the requirements placed on staff and what they actually do. However, as all enthusiastic programs to develop, foster, and evaluate safety culture show, the concept is very complex and requires specific knowledge. Both the technical staff of NPPs and the regulatory bodies were very familiar with solutions for technical problems, but they lacked the language and knowledge necessary to deal professionally with safety culture issues. The tool to be used by those working in the technical domain must be more practical and more pragmatic.

A new term appeared in the nuclear world toward the end of the 1990s: safety management. *Management of Operational Safety in Nuclear Power Plants* published by INSAG (1999), comprehensively describes the properties of safety management as an integral part of quality management. Many procedures of NPP quality management systems contain important elements that are needed to operate a plant safely and reliably. These fundamentals are part of the daily activities and, therefore, are routine to the majority of the staff. This situation implies a potential danger: they could lose the attention needed, and their efficiency may decrease.

Safety management is a concept that increases awareness of safety issues. This process may be achieved through special training programs, safety initiatives, and discussions on specific safety issues that are required by a safety management system. Safety management is a tool for fostering safety culture. In contrast to safety culture, safety management is tangible. It can be described. Safety management measures are concrete.

AN APPROACH FOR REGULATING ORGANIZATIONAL ISSUES

Regulation in the technical domain basically involves the definition of specifications and preconditions for the operation of NPPs. The corresponding technical limits can be defined through numbers and straightforward descriptions. The threshold for intervention by the regulator may be defined rather easily. When it comes to the regulation of issues related to human and organizational factors, however, specifications and norms are not available. What, for example, is the acceptable number of staff in an NPP? What is a reasonable number of shift crews? What is the appropriate organizational structure of an NPP? What is the minimum amount of training necessary for safe operation? Answers to these questions require detailed analyses of the present situation. In addition, the answers will be specific to each NPP.

In addition to this aspect of human and organizational factors, any intervention by the regulator has an influence on the members of the NPP organization and, subsequently, on the safety of the plant. Depending on the content of the intervention and on the way this intervention is performed, the influence on the utility may be more or less severe, and the effect may not necessarily be the way it was intended. The relationship between regulator and operator, an understanding of each other’s role, and the details of the interaction influence the result of the intervention in a manner that is difficult to control. This circumstance applies for regulation in the technical domain, but even more so for the regulation of organizational issues.

It is the responsibility of the regulator to take this difficulty into account and to develop the necessary questioning attitude when developing new regulatory rules with respect to human and organizational factors. The regulator may identify weaknesses, but in order to keep the responsibility for the safe operation of the NPP with the operator, the regulator should never be allowed to bring up specific solutions. The solution to the problem must remain the responsibility of the operator. How, then, can one go about regulating human and organizational issues? What should the requirements for operators be? What are the tools?

The Swiss approach to regulation of human and organizational factors

HSK issued regulatory guidelines for the organization of NPPs in 1986. The document basically described the status quo of the organizational structure of the Swiss NPPs. Over the next ten years human and organizational factors became an increasingly important subject in the field of nuclear power generation, with several developments acting as a catalyst for this shift.

1. The term "safety culture" was established in the nuclear industry.
2. The Convention on Nuclear Safety (IAEA, 1994) placed expectations on NPPs with respect to the organizational domain.
3. Various large modernization projects of NPPs were completed. The organizational units involved became obsolete, resulting in reorganizations at the plants.
4. The first generation of NPP staff began to retire.
5. The deregulation of the electricity market started to become a reality.

In this context the existing regulatory guidelines for the organization of NPPs were no longer able to cover all the dynamic changes in the organizational field. As a result, HSK decided to revise the document, bringing it up to date with the latest findings and developments in the field of human and organizational factors. The new regulatory guidelines should fulfill the following requirements: (a) reflect the state of the art of organizational and work psychology, (b) be practical and understandable for users (i.e., engineers), (c) be flexible enough to be applied to current developments as well as developments anticipated for the future, and (d) clearly leave the responsibility for operational safety with the operator.

HSK was highly involved in the development of different documents in the field of human and organizational factors. The input of experts and a literature survey complemented the knowledge in this area. Based on this information, "safety management" seemed to be the most suitable concept for a definition of the content of the new guidelines. The INSAG document *Management of Operational Safety in Nuclear Power Plants* (INSAG, 1999) was found to be the most comprehensive description of safety management in the nuclear field, and it became the main document for drafting the guidelines.

Because organizational changes are more likely in the future, HSK decided to emphasize a special aspect of safety management: organizational change. A special chapter of the new regulatory guidelines is devoted to the management of change. HSK requires an analysis for major organizational changes (in- and outsourcing, restructuring, significant staff reduction, etc.). Functions significant for safety must be maintained, and the utilities must demonstrate that the future situation will bring at least the same safety performance as the present one. The persons affected by the organizational change must be involved in the modification process early on, and the changes must be carried out smoothly. During the transition, the performance of the organization must be monitored very carefully in order to allow for early intervention in the event of a deterioration in performance. Basically, the HSK requirement is very simple: operators must deal with organizational changes just as carefully as they do technical plant modifications.

The project

HSK decided to carry out the project of revising the guidelines thoroughly, drawing from expertise in several areas. The project leader, an organizational and work psychologist, decided to include state-of-the-art knowledge from the organizational sciences. Consequently, experts from the Institute for Work and Organizational Psychology at the Swiss Federal Institute of Technology participated as members of the project team. The necessary technical knowledge was provided by different members of technical sections at HSK and by a working group delegated by the Swiss Nuclear Safety Commission. Accordingly, the development of the draft document was a highly interdisciplinary task. Already during this stage, the team members recognized difficulties that arose through the different approaches and terminologies used in the different disciplines.

The draft was then presented to the Swiss operators for comments. The results were impressive. The operators presented a list of about 80 recommendations and suggested discussing them in a meeting between representatives of the operators and the project team. Once more it appeared that misunderstandings and the different terminologies used were the main cause for the majority of the comments. The discussions were fruitful, and most of the questions could be resolved and recommendations implemented. This meeting contributed to a significant improvement of the document by enabling a common understanding of the regulatory expectations. In July 2002 the regulatory guidelines for the organization of NPPs went into effect (HSK, 2002).

A typical set of questions regularly came up in discussions during the drafting period. With what standards should the inspection findings be compared? What is the threshold for "acceptable" or "unacceptable"? Could the guidelines provide more precise definitions? For the most part these questions emerged from different understandings among the various disciplines in the team, yet the need for improved specification on certain issues was recognized. Terms like "adequate," "sufficient," and "enough" enable a common understanding, but in order to evaluate a certain situation they may be too vague. Therefore, the project team took this difficulty into account very early in the project. The solution to this problem was provided by a handbook to the regulatory guidelines (Grote, Humbel, Künzler, & Frischknecht, 2003). Like the regulatory guidelines, the handbook was a product of intense collaboration between experts in the field of human and organizational factors, technical specialists, and operators. The handbook builds on the beneficial experience gained through the first project.

Lessons learned

The document was prepared by social scientists with research activities and a great deal of experience in the area of organizational development. Their benchmarks were the INSAG document *Management of Operational Safety in Nuclear Power Plants* (1999) and the NPPs' existing internal regulations. Yet the language in the first draft of the document was not the language of technical engineers. The complicated discussions with HSK inspectors and managers (engineers and natural scientists) revealed differences between the disciplines: differences in conceptualization, language, understanding, and approaches.

The main difficulty was that the technical people were looking for well-defined limits for regulation, thresholds for intervention, indicators of good and bad, and so on. They tried to apply the technical approach to regulation (i.e., technical specifications) to the regulation of organizations. The psychologists, on the other hand, aimed for a more holistic approach, looking more at processes than at results and taking into account different aspects of the organization and factors that may be correlated or combined. The same difficulty came up again when the draft document was presented to the operators. Moreover, this time the difficulties were enhanced because the operators were the future subjects of the regulation.

Thanks to the persistence of the project leader, the two disciplines were brought together for very fruitful, open, and frank discussions. The consequence of this interdisciplinary approach was a positive collaboration resulting in a product that was favorably accepted by all parties. It was recognized that regulation in the area of human factors cannot be handled like technical regulation. NPPs are complex socio-technical systems. All related aspects require a professional approach—professionalism in the technical area as well as in the area of organizational sciences. Nuclear engineers must accept that they are not the specialists to deal with organizational issues. Both disciplines must accept that there are different languages and other barriers to overcome. Open and frank discussions, as well as continued efforts for a common understanding, certainly help overcome these difficulties.

CONCLUSION

Challenges to nuclear organizations may be triggered by external factors or by internal developments. Safety management is a valuable and effective tool to cope with these challenges. The high level of potential danger of nuclear facilities requires that all aspects of safety management be dealt with in a professional manner. Safety management is a valuable instrument for attending to all issues that maintain safety barriers in a good and reliable condition. It involves both organizational and technical aspects. The approach ultimately requires interdisciplinary collaboration between technical specialists and specialists in human and organizational factors. NPPs are still a mainly technical domain. Technical engineers still tend to handle human and organizational issues. Specialists in the field of human and organizational factors are, by contrast, rare within the nuclear community.

In order to implement sound safety management in nuclear installations, the following requirements must be taken into consideration:

1. There is a need for professionalism in the field of human and organizational factors. Organizational changes (modifications in the area of human and organizational factors) must be handled just as carefully and professionally as technical modifications (project development and project management). The involvement of specialists in human and organizational factors is highly recommended.
2. There is a need for an integrated interdisciplinary approach. Different disciplines must collaborate. Technical engineers and specialists in human and organizational factors must work together.
3. There is a need for an open and frank relationship between regulators and operators. Fundamentals of this relationship include good communication, transparency and clear rules and requirements, and a good understanding and acceptance of each other's roles.

Under the above preconditions for sound safety management, the organizations of NPPs should be able to cope effectively with most of the challenges in a changing world.

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CHAPTER 2
CHALLENGES IN THE NUCLEAR INDUSTRY: PERSPECTIVES FROM SENIOR MANAGERS AND SAFETY EXPERTS

Björn Wahlström

This chapter discusses present and emerging challenges identified by senior managers and safety experts. Data for this international study has been collected in discussions, structured interviews, group exercises, and questionnaires as part of the LearnSafe project, funded by the European Commission. LearnSafe's main objective is to create methods and tools for supporting processes of organizational learning at nuclear power plants. Organizational learning has become increasingly important for the nuclear industry in its adaptation to a changing political and economic environment, changing regulatory requirements, a changing workforce, a changing plant technology, and the changing organizations. The project focuses on senior managers responsible for strategic choice and resource allocation. The first phase of the LearnSafe project concentrates on management of change, and the second phase concentrates on organizational learning.

INTRODUCTION

The nuclear industry currently faces many challenges that stem from changes in several domains: changes in the political and economic environment, regulatory requirements, the work force, plant technology, and the organization of nuclear power plants and power utilities. Nuclear utilities and plants have tried to cope with these changes by initiating their own processes of change, which in turn have brought on a number of new safety issues connected to organization and management which need to be resolved.

The Technical Research Centre of Finland (VTT) has initiated and participated in several projects that investigate the relationships between nuclear safety and organization and management. These projects have included the project "Organisational Factors: Their Definition and Influence on Nuclear Safety" (ORFA) (Baumont et al., 2000), funded by the European Union, and activities in the NKS/SOS-1 project "Safety Assessment and Strategies for Safety" (Andersson et al., 2002), funded by Nordic Nuclear Safety Research (NKS). In these projects, an ongoing discussion about the challenges that must be responded to on a medium term have been taking place between researchers on the one hand and senior managers and safety experts from nuclear power plants on the other.

These discussions and perceived needs for more in-depth research (Wahlström, 2001) led to the formation of a new international consortium, which sought and obtained funding from the Nuclear Fission Safety section of the Fifth Framework Programme of the European Union. The "Learning Organizations for Nuclear Safety" project, or "LearnSafe," was started November 1, 2001, and ran for 30 months. It involved a total of 15 partners from five European countries and two international organizations. The first phase of the

LearnSafe project (see Wahlström et al., 2002) concentrates on change management, and the second phase concentrates on organizational learning.

The initiation of the LearnSafe project was part of a systematic effort at VTT to support the nuclear field in Finland with the competency needed to operate the four reactors at the Loviisa and Olkiluoto sites (Wahlström et al., 2000). One important aspect of VTT's skills and know-how related to the nuclear field has been built and maintained through publicly funded research and development, which has been carried out in four-year research programs (Kyrki-Rajamäki, 2002). The knowledge and competencies acquired through these efforts will be further used and developed in the construction of the fifth reactor in Finland, which was accepted in the Finnish Parliament on May 24, 2002.

THE LEARNSAFE PROJECT

The consortium

The consortium has created a unique partnership (see Table 2.1). The group of partners, which represents a broad spectrum of experience in nuclear activities, has joined to form an international consortium aimed at research in issues related to organization and management. The research has great potential to improve both safety and efficiency at the plants. Moreover, the formation of the consortium indicates a break with the traditional emphasis on technical aspects of nuclear safety.

Table 2.1 LearnSafe partners

1.	Technical Research Centre of Finland, VTT Industrial Systems (VTT)	Finland
2.	Berlin University of Technology—Forschungsstelle Systemsicherheit (TUB)	Germany
3.	Lancaster University (ULANC)	UK
4.	The Research Centre for Energy, Environment and Technology (Ciemat)	Spain
5.	SwedPower AB (SWP)	Sweden
6.	UNESA	Spain
7.	World Association of Nuclear Operators (WANO)	
8.	Teollisuuden Voima Oy (TVO)	Finland
9.	Forsmark Kraftgrupp AB (FKA)	Sweden
10.	Kernkraftwerk Grafenrheinfeld (KKG)	Germany
11.	Kernkraftwerk Krümmel (KKK)	Germany
12.	British Nuclear Fuels plc (BNFL)	UK
13.	OKG Aktiebolag (OKG)	Sweden
14.	Ringhals AB (Ringhals)	Sweden

Some of the partners cooperated successfully in the earlier ORFA project. As a result of the emphasis on nuclear utilities, partners in the ORFA project that represent regulatory bodies were not given a position in the present consortium. This does not mean that regulatory bodies are denied access to generic project results; on the contrary, they shall be invited to participate as discussants at LearnSafe seminars. Access to generic project results is given through a public web site.

The research-and-development organizations involved in the project have long been interested in issues of organization and management for safety in the generation of nuclear power. Some of them are involved in consulting to the nuclear industry and thus are in a good position to support the technological implementation of project results. In addition, the participation of universities enables them to include the early results from the project in their curricula, which facilitates the immediate preserving of knowledge in the field of safety management of nuclear power. The overall emphasis on safety and efficiency is assumed to provide students with a relevant introduction to business activities in the nuclear industry.

Hypotheses of the project

The LearnSafe project is concerned with organizational learning within the nuclear industry. LearnSafe partners are aware that this theme has been studied within the management sciences and that it has been applied in high-risk industries such as transportation, chemicals, and offshore activities. In starting up the LearnSafe project with funding from the Fifth Euratome Framework Programme of the European Union, the partners believed that demands set on the nuclear industry were unique enough to warrant a dedicated study.

The following observations point to just some of the considerations specific to the nuclear industry which set it apart from other high-risk industries:

1. Nuclear reactors require continuous supervision, because even when they are shut down the removal of residual heat must continue to function.
2. Societal concerns about risks connected to nuclear power are greater than actual risk estimates, such as those provided through probabilistic risk assessments.
3. With regard to safety, a nuclear power plant has a higher burden of proof than do other high-risk applications.
4. The nuclear industry is a global industry in that bad performance anywhere is likely to lower trust and confidence in the industry everywhere.
5. Even the suspicion that a nuclear power plant is not safe may be enough to shut it down for extended periods.

In setting up the LearnSafe project the assumption was that senior management has an important influence on the safety of their plants. Hence, the chosen focus for the project was those senior managers at nuclear power plants and at the corporate level who are responsible for strategic choices and the allocation of resources. Observations and discussions confirm that many unique demands are placed on senior management in the ongoing process of adaptation to changed operational conditions. In this connection it is necessary to understand how safety threats can emerge and grow from seemingly unimportant details, becoming problems that pose risks to the business.

Objectives of the project

The main objective of the project was to create methods and tools for supporting processes of organizational learning at nuclear power plants (NPPs). This goal was selected in view of the importance of organizational learning during a process of change management. In recent years the nuclear industry has been forced to adapt to a changing political and economic environment, changing regulatory requirements, a changing work force, changing plant technology, and changing organizations at the power utilities. A sustainable strategy for the continued operation of European NPPs depends on a successful adaptation to all these changes without compromising safety in any instance.

The main objective can be broken down into secondary objectives. Directly connected to the main objective and focus of the project is the need of NPPs and power utilities for practical methods and tools to support their senior management during processes of organizational change. Such methods and tools support the early identification of emerging issues and challenges. Project results also support ongoing change processes by indicating issues that must be considered more carefully than others.

Another objective of the LearnSafe project was to create a close interaction of researchers and practitioners in order to stimulate a search for and exchange of innovative solutions for organization and management. It is believed that such interactions within the project can help in finding new solutions that enable safety management activities to become increasingly efficient.

The project is expected to have an important impact through the collection and documentation of managerial experience from the participating NPPs and through reflection on that experience by means of available theoretical frameworks from the management sciences. The project also aims to be instrumental in feeding this information back to the participating NPPs in the form of seminars and training courses for younger managers.

Research questions

The first empirical and theoretical phase of the project was devoted to change management, in recognition that various mechanisms of change bring new challenges to the senior management at the NPPs. This led to the formulation of the following research questions for the first phase of the project:

1. What are the perceived emerging challenges in the management of NPPs?
2. How do senior managers cope with emerging challenges in the management of NPPs?
3. What improvements could be made with respect to coping with emerging challenges in the management of NPPs?

The project's second phase was connected to the concept of learning organizations. A considerable amount of research within organizational and management sciences has been devoted to investigating how learning occurs and what characteristics facilitate organizational learning. At this stage the following preliminary considerations provide indications of the direction of the research during the second phase:

4. What kinds of features and attributes characterize learning organizations?
5. What are the most common barriers to organizational learning and how can they be removed?
6. How are various company cultures and subcultures influencing organizational learning?

Project expectations

One expected result of the project was that it will bring about fruitful interactions between theory and practice. The cooperation between national partners provided contributions to the project which enable cross-cultural comparisons. In addition to these interactions, the partners were encouraged to establish direct connections between each other for the in-depth investigation of interesting issues. Moreover, early results from the project were to be adopted in trial applications at the participating NPPs.

Among the participating NPPs there were expressions of interest to share views on safety management between organizations and countries. A number of interesting questions in this regard might be addressed, such as:

– What activities are seen as important in safety management at NPPs, and how are they connected to other activities?
– Is it possible to set performance standards on safety management activities?

One issue brought up within the project was the possibility of organizational drift. This concept refers to cases in which organizations have drifted into unacceptable situations through a series of decisions that may have been rational in the small but, when taken together, prove to be pernicious, dangerous or destructive. Interesting questions in this case address, for example, under which conditions such organizational drift may occur and what indicators may be used as warning signals.

One important result of the LearnSafe project is a collection of good practices. In their most generic form such practices may even be called organizational safety principles, in correspondence with similar technical safety principles such as the defence in-depth principle and the single failure criterion. If organizational safety principles could be identified, they would have many applications. They could, for example, be used to formulate organizational requirements on safe operation in order to support analysis and review. They could also provide a basis for developing methods and tools for organizational self-assessments.

CHALLENGES WITHIN THE NUCLEAR INDUSTRY

What do we mean by challenge?

When looking up a dictionary definition of the word "challenge," one finds definitions such as

(a) summons to engage in a contest,
(b) a call to fight in a battle or duel, or
(c) difficulty in an undertaking that is stimulating to one engaging in it.

These definitions quite aptly describe the situation of the nuclear industry today. There have been many changes in the political and economic environment, in regulatory requirements, and in the work force available on the labor market, all of which pose a challenge to be met. Some of these challenges have been approached by introducing new technologies and by restructuring organizations and ownership at the NPPs and power utilities. These strategies have, in turn, brought on a series of new challenges for senior managers to consider.

Challenges in a cause-and-effect relationship

Challenges are seldom issues that can be approached and coped with in isolation. They are more often complex issues with a multitude of causal relationships, which can be approached at various levels and within different time frames. In order to create efficient coping strategies for approaching these challenges, senior management at NPPs must have a kind of relational model of how the issues interact. In its most simple form one could consider one single step in a causal chain and speak about preconditions for conditions or events. A condition or event may, in turn, have a number of consequences that must be taken into account. Using this simple model to trace relationships between various challenges, one can immediately see that a challenging issue may be either a precondition or a precursor to another challenge and that actions taken to cope with a certain challenge may have a number of other challenges as their consequence.

Challenges may also be considered in terms of a scale ranging from general to specific. To give one example, the creation of awareness and understanding in an organization may be regarded as a very general challenge applicable to many situations. On the other hand, the selection of appropriate methods and tools for implementing an organizational change may be considered a far more specific challenge. One might even hypothesize that specific challenges can be described by using more general challenges.

Data collection

Data collection for the first phase of the LearnSafe project concentrates on processes for the management of change at the NPPs. To support the data collection phases, a list of challenges (see Table 2.2) was generated within the LearnSafe project; this list was based on literature and partners' previous experiences. This list has been used to stimulate discussions during the data collection sessions.

The following groups of people have participated in the data collection so far:

(a) experts (nuclear safety, occupational safety, regulators),
(b) top management from the utilities (vice president of nuclear power operations, chairman of the board),
(c) members of upper management at NPPs, and
(d) multifunctional managers (operations, maintenance, technical, quality/safety, radiation protection, chemistry, human resources management, training).

The first group participated by judging the list of challenges as generated by the LearnSafe project according to two dimensions: importance and time frame of influence. Semi-structured interviews were used for the second group, and for the last two groups Metaplan sessions were used to collect challenges and structure them into clusters.

Table 2.2 List of challenges as generated by the LearnSafe project

1.	Aging personnel
2.	Contractor competency and skills
3.	Recruiting young people
4.	Motivational problems
5.	New regulatory requirements
6.	Pressures from owners and higher management
7.	Adapting to the role of a skillful customer
8.	Public confidence
9.	Changes in company ownership
10.	Focus on short-term goals and performance
11.	Deregulation and competition
12.	Human and organizational factors
13.	Cost pressures as compared to competing energy sources
14.	Internal debiting for services
15.	Requirements on formalization and documentation
16.	Negative publicity
17.	A decreasing number of vendors

18.	Differences in national regulatory requirements
19.	Handling nuclear waste in a short-term perspective
20.	Asset management when there are multiple owners
21.	New technologies
22.	Loss of confidence in national and international regulators
23.	Diverging views between regulator and utility
24.	Aging plants
25.	Decommissioning of plants
26.	Terrorism and sabotage
27.	Dissimilarities in regulatory philosophy by different authorities
28.	Maintaining nuclear competency
29.	Changing societal priorities

In the Metaplan session the participants are first asked to fill in three to five short sentences on small cards in response to one question posed to the group. The cards are then collected, read out loud, and pasted on the wall for all to see. The next step is to rearrange the cards to form clusters, which are given names according to a consensual suggestion from the participants. Finally, the clusters and statements are evaluated according to their importance. Obviously, there is some room for variation in how the Metaplan sessions can be carried out; this description is meant to give a general idea.

In the actual Metaplan sessions at the NPPs the question posed was research question one (see above). As an intermediate step in the Metaplan sessions, before moving to the formation of the clusters, the LearnSafe list of challenges was used to ensure that a reasonably complete picture had been obtained. The Metaplan sessions took about 1.5 hours and involved about ten persons each.

Preliminary results

The following results are based on results from Finland and Sweden, when about 90% of the data were collected. These preliminary results are not based on a thorough analysis, but may still reflect some interesting qualitative impressions from the material.

Overall, the list of challenges collected by the LearnSafe project has covered the challenges as perceived by different persons within the industry reasonably well. Some of the issues brought up during the Metaplan sessions led to an increase in the number of challenges and suggestions of additional cause-and-effect relationships. One comment on the LearnSafe list of challenges was that they were rather detailed in comparison with the more general issues to which managers devote their attention.

The expert opinions from Finland on the LearnSafe challenges were quite similar. The most important challenges were (1) aging personnel, (8) public confidence, (24) aging plants, (28) maintaining nuclear competency and (21) new technologies (see Table 2.2). The challenges of (13) cost pressures from competing energy sources, (22) loss of confidence in national and international regulators, (25) the decommissioning of plants and (19) the handling of nuclear waste in the short term were viewed as rather unimportant. The most urgent challenges to be dealt with were (10) a focus on short-term goals and performance, (15) requirements for formalization and documentation and (21) new technologies.

Top management in the utilities identified issues related to competency, deregulation, aging and renewal of the plants, and management of safety as the main challenges. They were unanimous in seeing the largest challenge facing the nuclear industry as the ability to maintain competency in the nuclear field worldwide. All saw a new upswing for nuclear power in the future, but feared it might take time.

The Metaplan sessions have generated large data sets, and final analysis of the material was started after the data collection was completed. Some qualitative observations can be made. First, there are considerable similarities in the material. Second, the clusters and challenges seem to fall well within the following larger metaclusters: regulators; aging, modernization, and new technology; economy; competency; management and organization; and society.

A set of generic challenges

In an attempt to identify generic challenges from the material, a helpful approach is to consider the balances between contradictory demands (see Table 2.3) identified by the ORFA project. The balance between economy and safety can clearly be seen in the responses, as an instance of the balance between costs and benefits, which requires management to take a position on how much it is willing to spend resources on certain issues of importance. In the regulatory domain there seems to be a need to balance between tradition and renewal, a circumstance in part connected to regulators' hesitation in the face of new organizational structures.

For nuclear utilities, the balance between cooperation and competition has shifted with deregulation, and it may be necessary to take this situation into account when the challenges are addressed. Earlier there had been a decentralization of nuclear organizations, but it now seems the pendulum has swung in the direction of more centralized organizational forms. The balance between discipline and flexibility emerges with the issue of the renewal of quality systems; the need for providing a better overview also has been identified with respect to this issue.

Table 2.3 Balances in management

Conservative	Liberal
Traditions	Renewal
Formality	Informality
Self-confidence	Willingness to listen
Cooperation	Competition
Centralised authority	Distributed authority
Discipline	Flexibility
Focus on details	Maintaining an overview
Monitoring and reporting	Confidence and accountability
Short-term optimization	Long-term optimization
Specific/practical	Generic/theoretical

Fears have been expressed that ownership and responsibility may be weakened in the process of organizational change, which may indicate the need to give adequate attention to the balance between monitoring and reporting, on the one hand, and confidence and accountability, on the other. There are also fears that cost pressures may introduce short-sightedness in decision-making at the plants. In consideration of the need for a long-term outlook with regard to investments in plant renewal and employee competency, this development could be counterproductive for the nuclear industry as a whole.

STRATEGIES FOR COPING WITH THE CHALLENGES

Regulators

The issues addressed on this point were related to new regulatory requirements under development. Another issue that was raised is related to the role-play between the regulator and the NPPs. Some also touched on the fear that the focus of the regulator may shift away from issues that are relevant for safety only and include formalities that are not considered necessary. In this connection it is also necessary to note that it is not only the safety authorities that place requirements on NPPs but other authorities as well, which issue requirements on environmental protection, labor safety, competition, and so forth.

One issue mentioned in this connection is that it has been somewhat difficult to agree on a suitable safety standard for old reactors which takes due consideration of the costs involved in bringing them up to modern standards. Another problem is related to the licensing of programmable instrumentation and control systems, an area where considerable difficulties have been encountered.

Many participants mentioned the need for a harmonization between regulatory requirements, especially in consideration of the fact that nuclear utilities in Europe compete on the same markets. The establishment of the Western European Nuclear Regulatory Association (WENRA) was welcomed in this regard. Generally, it was believed that better international cooperation in comparing and assessing systems of requirements could help in coping with some of these challenges.

Aging, modernization and new technology

These issues are related to the need to follow and predict when certain components must be replaced. This requires careful optimization of the remaining life span of main components and will also involve the introduction of new functions using advanced instrumentation and control systems. The increasing obsoleteness of certain components has forced plants to modernize. In some cases these modernizations have been connected with safety requirements, which have made it cost-effective to replace old materials with new ones.

These issues were viewed as important, but relatively well under control. There are efficient methods and programs for following the aging of main components. Many plants have voluntarily initiated large-scale modernizations, with the aim of extending plant lifetime far beyond 40 years. One major difficulty seems to be finding agreeable methods for the licensing of programmable instrumentation and control systems.

Economy

The deregulation of Europe’s electricity market has increased pressures to decrease costs at NPPs. This pressure is attributed sometimes to owners and sometimes to companies’ upper management. Continued safety depends on conservative decision-making, which also builds trust and confidence between the NPP and the regulator. Many individuals pointed to the danger that a conflict may emerge between economy and safety, but others pointed to the need for a good economy in order to maintain the safety of plants.

Deregulation in Finland and Sweden occurred in 1995–1996, a period characterized by a large surplus of hydropower in the Nordic system, which put more strain on the adaptation process. It seems that some plants have had greater difficulties than others in their adaptation to the deregulation of the electricity market. Most participants, however, expressed satisfaction with the present situation, though they also pointed out that the issue requires continued efforts. So far no plant had experienced difficulties in getting their investment programs accepted by their boards.

Competency

Competency was a theme brought up by all respondent categories. One concern was connected to maintaining competency at the NPPs in view of the future generation changes foreseen for many European plants. One special challenge in this connection is to select and train senior managers for the nuclear industry. A second issue was connected to the competency of vendors and contractors, and some respondents expected a possible increase in prices if competition were to disappear. Some concern about the competency of regulatory bodies was also voiced. More generally, many felt that maintaining competency in the entire nuclear field is the greatest challenge currently facing the nuclear industry.

At the plants the competency issue has been addressed in many ways. All plants have initiated projects to create an inventory of their own competencies together with a projection of the expected situation in the future in order to identify possible gaps and the need for action. One organization has even brought in the average age of the employees to be monitored, using this as a performance indicator.

The competency of major vendors was especially seen as problematic. Recently, there have been mergers among them. Some persons expressed satisfaction with this concentration of resources. Still others expressed a fear that it may lead to a weakening of competencies in the long term. The competency of contractors was seen as somewhat easier to cope with; some NPPs, for example, systematically employ contractors in long-term contracts in order to reinforce the development of their competency and skills.

Management and organization

The development of management practices and organizational structure was perceived as a major challenge. Some expressed a fear that frequent organizational changes may weaken ownership and responsibilities. The curtailment of complacency was also considered an important challenge. Mention was made of the special challenge of maintaining employee alertness even when plant performance is good and has been good for several years. Many comments on the importance of maintaining a sound safety culture were made in this regard.

Many of the NPPs have gone through organizational changes as part of a strategy to become more efficient. Many indicated that they had been successful in their rationalizing efforts. Some plants have outsourced some peripheral activities, but this strategy has not been very common in Finland and Sweden.

Many plants have implemented major changes in their quality systems, in part with the intention to become more efficient and in part to make procedures and practices more transparent. In the transition to increasingly integrated systems for activity planning and implementation, which many of the nuclear power plants now use, the so-called balanced scorecard concept has been utilized for goal definition and follow-up.

Society

The need to maintain confidence among the local and national public was mentioned by many participants. The importance of openness in communicating with the media was stressed in this connection. Political issues, such as taxes, can have a considerable influence on many of the other challenges and can easily make a difficult situation worse. Another consideration was the need to take into account the possibility of terrorism and sabotage.

Public trust and confidence in the NPPs in Finland and Sweden seem to be well established. Polls from Sweden, for example, reveal that there is much greater support for nuclear power from the public than from the political establishment. Many NPPs conduct regular polls to assess public opinion, both regionally and nationally. The plants have good relationships with the regional authorities, providing information and supporting various local activities. The political gauntlet leading to the premature closing of one plant in Sweden was considered grotesque and not in support of safety at the rest of the plants.

CONCLUSION

NPPs today are faced with many challenges. It is apparent that these challenges are matters that require continuous management attention and that various approaches to address them have been taken. A satisfactory resolution of some of the challenges may require a coordinated action from several nuclear operators, but the competitive situation today may make such actions more difficult. It is clear that the challenges currently facing managers at NPPs have increased the burden on people. Fortunately, at the same time, new ways to structure work, new tools, and new management practices have been found to make the use of resources more efficient.

Initial results from the LearnSafe project support the conclusions of earlier projects showing that research addressing issues related to management and organization is important. Discussions with senior managers also tend to confirm that they have a tremendous number of issues to which they must attend. At the same time, earlier research has demonstrated that incidents seldom are the consequence of some major mistake or error, but rather are the outcome of a large number of seemingly minor issues that are combined to create an unlucky coincidence (Hollnagel, 2002). This finding implies that senior management must approach all details with similar rigor to ensure that no hidden deficiencies are introduced into the systems.

Discussions within the LearnSafe project have tended to confirm anecdotal evidence that senior managers greatly influence organizational culture. It is therefore important that they be aware of the impact that minor slips can have and that these slips are responded to and acted on with necessary force and efficacy. In the larger picture it is hoped that the LearnSafe project will contribute to the awareness and understanding that is needed to maintain a good safety record. This safety record is crucial for continued public support of nuclear power and, thus, also an essential factor in the efficient use of available energy resources in Europe.

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CHAPTER 3
SAFETY CULTURE FOR THE DECOMMISSIONING PROCESS

Michael Baram

When nuclear power plants are shut down for reasons of safety, cost, or politics, each plant must undergo a costly and complex decommissioning process in accordance with regulatory requirements before regulators may determine that the site does not pose an unreasonable risk and the plant may be sold or transferred for a new use. Recent experience indicates that the decommissioning process is more than an engineering or technocratic exercise. It involves conflicts between regulators, confusion over differing standards governing human exposure, public mistrust and fears about residual risks, local politics about future use, the expectations of future owners and users of the site, and opposition to on-site storage of spent fuel. Thus, the new organization created to manage a decommissioning process is likely to be challenged by many socio-technical issues and by external parties with competing interests. The safety culture concept, which emphasizes a holistic approach to the social, behavioral, and technical aspects of safely operating nuclear power plants, may prove useful when extended and adapted to the decommissioning process.

THE DECOMMISSIONING OF NUCLEAR POWER PLANTS

Over the last decade, several countries have taken steps to close facilities that produce, use, or store nuclear materials. Germany and Sweden have enacted laws that aim to phase out nuclear power production (Brewitz & Sailer, 2002; Lofstedt, 2002). In the United States and other countries, major programs are being carried out to close many nuclear installations that had been used for military purposes.

In addition, owners of nuclear power plants have voluntarily decided to shut down several facilities and sell or transfer the sites to new owners for industrial, commercial, recreational, or other uses. These voluntary decisions usually apply to older plants that are inefficient and pose safety problems; in most cases the decisions are driven by financial considerations. A conservative global estimate is that by 2010, some 300 nuclear power units will have outlived the operational lifetimes for which they were designed and will become likely prospects for shutdown (Organisation for Economic Co-operation and Development [OECD], 2002).

However, an owner's ability to sell or transfer a site after shutdown depends on the successful completion of a decommissioning process, which involves the demolition, cleanup, and removal of radioactive material and other hazardous substances; safe storage of spent fuel; and the approval of several government agencies responsible for ensuring the protection of workers, public health, and the environment (Nuclear Regulatory Commission, 2002a; OECD, 2002). Thus, the decommissioning process is intended to serve two related purposes: to ensure that the site will not pose unacceptable risks during and after its cleanup and to enable the owner to sell or transfer the site so that it can be safely used for other purposes.

In the United States the licensing agency for nuclear power plants, the Nuclear Regulatory Commission (NRC), requires owners to establish a trust fund at start-up of plant operation to ensure that adequate funds will be available to pay for the decommissioning process when needed, or, alternatively, to post surety bonds as a financial guarantee (NRC, 2002b). Trust funds at older plants now exceed several hundred million dollars (NRC, 2002b). If the actual costs of decommissioning are less than the amount in the fund account, the owner retains the unused amount as a financial gain, although state law or regulation may require that the unused funds be shared with other parties, such as former customers of the electricity once produced. If, however, the costs of decommissioning exceed the fund amount, the owner must provide the additional financing needed to complete the decommissioning process before the site can become eligible for sale or transfer. A recent estimate of cleanup costs at German plants indicates that these costs will range from DM 690 million to DM 770 million (Mertin & Hortmann, 2002; the estimate corresponds to about 350 to 390 million euros as of Fall 2003), an amount roughly equivalent to current cost estimates in the United States. Thus, owners everywhere aim to contain the costs of the decommissioning process (Ronningen, 2002).

The decommissioning process is complex and costly. It must be managed so that radiological, chemical, and other risks to workers, the public, and the environment are prevented during the cleanup process. It also must accomplish site cleanup to an extent adequate enough for the NRC to permit the owner to sell or transfer the site to other parties for new use. Consequently, the NRC and other agencies must be convinced that any residual risks that remain after cleanup and transfer will not endanger future owners, occupants, and visitors. Thus, the decommissioning process requires careful analysis of many short- and long-term risks so that both its implementation and its outcome comply with numerous risk regulations and standards established by national, state, and local agencies. In addition, public perceptions and concerns must be addressed, because any concerns that remain about the outcome and its residual risks will adversely affect the value of the site and frustrate the owner’s ability to sell or transfer it for new use.

Up to now four plants have been fully decommissioned in the United States, and several others are in various stages of the decommissioning process (NRC, 2002b). Plants are also being decommissioned in many other countries: Tokai in Japan, Staade and Obrigheim in Germany, Barseback in Sweden, Krško in Slovenia, and several other plants in Eastern European countries. Thus, experience with the decommissioning process is growing, and new knowledge is being gained; however, because each plant has unique risk characteristics, extracting information of generic value from such knowledge and applying it to other decommissioning processes is difficult, for much of the knowledge is plant-specific.

However, it is clear that the decommissioning process in each case must be cost-effective and safe and must produce an outcome that satisfies the licensing agency, other regulators, the current owner, the community, citizen activists, and the prospective owners and users. It is also clear that responsibility for managing the decommissioning process lies with the owner and top management of the plant, persons who have prior experience in safely operating the plant but no experience with demolition and other tasks of the decommissioning process.

As the nuclear power industry in many countries moves further into decommissioning, it may be of value to managers of future decommissioning processes to determine the extent to which safety culture concepts and practices, developed for plant operation, may now also be extended to the decommissioning process. The extension and application of this concept may help these managers achieve their goals within the given financial bounds (Wilpert, 2001).

THE DECOMMISSIONING PROCESS AND SAFETY CONSIDERATIONS

In the United States the decommissioning process is a lengthy enterprise that may take decades to complete at each plant (NRC, 2002a). It starts with plant shutdown and disconnection of equipment and other operational features. The site cleanup process then commences and involves an extensive set of activities (Baram 2002):

(a) identification and measurement of radiological hazards and various chemical hazards (e.g., toxic, corrosive, flammable); contaminated equipment, structures, soils, and groundwater; hazardous supplies and wastes; and spent fuel;
(b) determination of applicable safety standards and risk regulations for cleanup tasks;
(c) collaboration with national, state, and local agencies with regard to determination of the standards and other regulations governing residual contaminants and risks that will be allowed to remain on-site after completion of cleanup tasks; efforts to address public concerns; and fulfillment of special requirements for the long-term storage of spent fuel and for security arrangements on the site until shipment off-site to a final disposal facility is approved by the national government;
(d) calculation of human exposure pathways, uptake, and levels of human exposure during cleanup with regard to worker protection, and after cleanup the anticipated future use of the site, its likely occupants and visitors, and the duration of their exposure to residual contaminants;
(e) creation of a cost-effective cleanup strategy that integrates and sequences multiple radiological and chemical cleanup tasks for optimal efficiency;
(f) coordination and management of effective implementation of the cleanup strategy and tasks; and
(g) final verification that the site will not pose unacceptable risks after transfer and during its intended future use.

Elements of the integrated cleanup strategy to be implemented include removal of fuel from the reactor and its transfer off-site; secure long-term storage of spent fuel on-site for an indefinite period; demolition of the reactor and other heavily contaminated structures, equipment, and piping; removal and packaging of debris, contaminated soil, chemicals, and wastes; remediation of other structures (e.g., removal of lead paint and asbestos) and contaminated groundwater; shipment of contaminated materials to appropriate disposal facilities (except materials that regulators have approved for on-site entombment or "free release"); and performance of monitoring, documentation, and reporting functions (Baram, 2002).

After the strategy has been approved by national, state, and local regulators, its implementation must be managed by an essentially new private organization comprised of plant officials, consultants, and contractors. Tasks must be allocated and coordinated among numerous independent contractors and their subcontractors, which range from firms with sophisticated risk analytic and health science expertise to firms experienced in heavy construction, demolition, and waste handling transport. All activities and outcomes must meet applicable safety and environmental standards and procedures and must be documented. Unforeseen problems, such as finding contaminated groundwater, and unintended incidents, such as spills and worker injuries, need to be reported and will require review by regulators, meetings, and costly changes in tasks and schedules. Pressures to contain costs will always be present: for example, to minimize the materials to be shipped off-site, to compact materials in order to reduce the volume of shipments, and to integrate radiological and chemical cleanup tasks in order to achieve efficiencies (Ronningen, 2002).

However, the decommissioning process is more than a technocratic activity. It is an open, public process in the United States, and this situation introduces additional complexities. Many national, state, and local agencies; citizens' groups; and various local business and property interests are involved. Diverse perceptions about risks, mistrust of regulators, competing demands, conflicts, and lawsuits may arise and be amplified by media coverage, thereby making implementation a much more complex process. Thus, management should be prepared to deal with a number of socio-technical problems that have psychological, political, economic, and legal aspects. An ability to deal with such problems effectively will require an organizational culture that foresees these issues and gives them sufficient regard and attention. Otherwise, the decommissioning process will be obstructed and become ever more costly.

A recent case study of the first decommissioning process in Massachusetts, now nearing completion after fifteen years, is instructive. It deals with the decommissioning process for a small nuclear reactor (5 MW) and its contaminated site in the city of Watertown, a Boston suburb. The reactor previously had been owned and operated by the U.S. Department of Defense for military research and related purposes. Several socio-technical problems were encountered when implementing the decommissioning cleanup strategy (Baram, 2002).

Determining future use of the site

Making this determination as early as possible is of critical importance because the type of use will determine which contaminants and residual risks regulators will allow to remain at the site after the property is transferred to a new owner. A future use that will expose persons to residual radiological and chemical risks for long periods, such as use for housing, or that will expose a population that is more vulnerable, such as children if the site is to be used for schools or playgrounds, will require very low levels of residual risks, and thus a very extensive and costly cleanup. In contrast, less stringent and cheaper cleanup, and more residual risk, will be allowed for future uses that involve less human exposure, such as using a site for the storage of products, parking, equipment repair, or, ironically, conservation and occasional outdoor recreational activities such as hiking and camping.

Thus, the decision about future use has a major influence on the extent of cleanup and the costs to be incurred by the owner. However, in the case of the Watertown reactor, making this determination proved to be a lengthy and contested process, which led to uncertainty and inefficiency in implementing the decommissioning process. The decision-making process involved city and state planners and officials; federal licensing and cleanup agencies (the NRC and the Army Corps of Engineers); federal environmental, state environmental, and public health agencies; several groups of concerned citizens and diverse business interests; the site owner and prospective owners of each of several portions of the site intended for sale or transfer; various consultants; and the state's senators in Congress.

Determining the regulatory requirements for site transferability

Determination of the regulatory requirements is another matter of obvious importance to designing and carrying out the cleanup strategy. Yet this task can be problematic when several agencies are involved and apply different standards and procedures and when citizens are mistrustful. In this case the national NRC standard for limiting human exposure to ionizing radiation (25 mRd/year above natural background) conflicted with the state's Department of Public Health standard (10 mRd/year above natural background), and both differed from the state's Department of Environmental Protection standard (1 in 100,000 excess lifetime cancer risk), which encompassed exposure to toxic chemicals and hazardous wastes as well as sources of radioactivity. This dysfunctional relationship between the three most important regulators caused further uncertainties in the decommissioning process and led to public confusion and mistrust. Subsequently, special initiatives were undertaken, and these measures succeeded in bringing about inter-agency reconciliation of differences, a troubled process that involved addressing legal considerations and differences in their regulatory cultures. A special program of public education restored some measure of trust in the cleanup process.

Addressing other regulatory and community concerns about risks

Throughout the decommissioning process, many concerns about risk had to be dealt with. For example, the discovery that shoreline contamination threatened an adjoining river required that a special long-term remediation and monitoring program be devised with state regulators and the community. Moreover, various initiatives had to be undertaken when it was found that there was public confusion and mistrust about post-transfer residual risks and the restrictions to be imposed on future public use of certain parts of the site. These initiatives included the provision of documentation on request, the creation of a documentation center open to the public within the community library, holding numerous meetings with citizens' groups and the community for hearing concerns and presenting expert views and explanations, the provision of resources to support a citizen advisory committee and the securing of its involvement in the decommissioning process, the provision of funds for this group to hire its own expert consultant for independent analysis of risk issues, and cooperation with health scientists at the national Centers for Disease Control in the conduct of an independent and comprehensive public health review.

Similar problems arise in the decommissioning process at power plant sites. However, unlike problems at the Watertown reactor, which was owned by the national government, problems at power plant sites must be dealt with by owners who have fewer financial resources. In addition, plant sites are subject to the special NRC requirement that spent fuel be kept on a portion of the plant site in a long-term storage facility until a national disposal site is approved and available for receiving such material (NRC, 2002b). The long-term storage facility, which may be water-cooled or may use new dry-storage technology, must be maintained by the plant owner in order to prevent accidental release, and it must be fenced and policed in order to prevent access by terrorists or other intruders. This requirement, which is costly and poses new risks, has triggered intense controversy and lawsuits by plant owners and by people living near sites being decommissioned (Cairns, 2001).

This case demonstrates that the decommissioning process must be managed by an organization that is capable of effectively addressing many risk issues that are not purely technological. Such an organization will need to be motivated to deal with the political, legal, psychological, and behavioral factors that underlie these issues. As a result, it must have technological expertise as well as skills in communication, education, negotiation, and dispute resolution.

ORGANIZATIONAL NEEDS AND THE RELEVANCE OF SAFETY CULTURE

The new organization that manages the decommissioning process will essentially direct a very large construction-type project in order to meet safety goals and other regulatory and public requirements within cost constraints. As discussed above, this project will involve coordinating numerous consultants and contractors and ensuring that they comply with appropriate procedures in order to minimize the risks involved in the cleanup process to workers, the public, and the environment. Ensuring this compliance is also critical to achieving an outcome in which the residual risks are acceptable, thereby enabling the site to be sold or transferred and put to new use. The project also will involve working harmoniously with numerous parties external to the organization, a considerable change from plant operation in which plant management had to deal only with a single external party, the NRC, its licensing agency.

These organizational characteristics and others discussed earlier all relate to ensuring safety—the term is used here to encompass risks to health, safety, and the environment which arise from accidents as well as from excessive exposure to toxic chemicals and radioactive sources over time. By aggregating these characteristics, it is possible to envision the development of a new safety culture concept that can be usefully applied to the new organizations responsible for planning and managing decommissioning processes. To move in this direction, it is necessary to begin with an understanding of what safety culture has come to mean in the nuclear industry and what its basic attributes are generally considered to be.

Safety culture is an aspirational concept that was formulated, following Chernobyl, to encourage continuous improvement in organizational performance in operating nuclear installations, thereby preventing catastrophic accidents. As illuminated by Wilpert and Itoigawa, the concept incorporates and merges two intellectual developments: the modern view of safety science that ensuring safety is a socio-technical undertaking because it is dependent on complex interactions of human and technical factors and the behavioral and psychological view that an organization's culture is the product of unconscious basic assumptions, shared values and norms, and observable artifacts and behaviors (Wilpert, 2001; Wilpert & Itoigawa, 2002).

Analytic work in safety science, an interdisciplinary field of study and practical application, has defined important features of safety management for complex technological systems, and many of these features are now assumed to be important attributes of safety culture. For example, Reason (1990) has emphasized the need for continual vigilance in identifying and correcting "latent failures" in managing a technological system, because such deeply embedded failures have the potential to incubate and ultimately produce an accident. Rasmussen (2001) has stressed the need for an organization to continuously work at preventing the subtle erosion of its defenses against accidents and the unconscious migration of its safety system toward accident occurrence. He maintains that these dangerous trends can be prevented by diligently evaluating the behavior of internal and external decision-makers and the information they exchange.

Turner and Pidgeon (1997) have concluded that a good safety culture is one that reflects and is promoted by at least four features: commitment by top management to safety; a shared concern among all members of the organization about its hazards and their human impacts; reliance on norms and rules that are realistic and flexible; and continual reflection upon practices through monitoring, analysis, and feedback systems. Wilpert and Itoigawa (2002) have characterized safety culture as a robust and dynamic learning process that involves all individuals and groups within the organization, as well as external parties such as regulators and other members of the societal infrastructure that enables organizational activities. They also suggest that the realization of a safety culture increasingly requires that the organization correct dysfunctional relationships between these external parties, as in the Watertown case.

Agencies and professional and industrial associations have sought to translate the safety culture concept into rules and procedures that can be routinely followed. In this regard, Meshkati (1999) has summarized the conclusions of an official governmental review of the NRC's comprehensive and highly detailed regulatory framework for nuclear safety.

According to the NRC, nuclear safety culture is a prevailing condition in which each employee is always focused on improving safety, is aware of what can go wrong, feels personally accountable for safe operation, and takes pride and ownership in the plant. Safety culture is a disciplined, crisp approach to operations by a highly trained staff who are confident but not complacent, follow sound procedures, and practice effective teamwork and effective communication. Safety culture is an insistence on a sound technical basis for actions and a rigorous self-assessment of problems (Meshkati, 1999, p. 63)

Nevertheless, many analysts are skeptical about such reductionist approaches because they believe that the safety culture concept is too vital and dynamic to be simplified in mantras and procedural manuals.

Thus, there are diverse but not inconsistent visions of safety culture, all of which have been developed for the purpose of encouraging organizations that manage nuclear installations to continually improve their methods of preventing catastrophic accidents. There is no apparent reason why the concept of safety culture cannot be adapted and promoted to similarly encourage the new organizations that manage decommissioning processes to improve their performance in preventing accidents and minimizing harm to health and the environment from exposure to radioactive and toxic chemical sources.

Adaptation of the concept would involve tailoring it to fit both the special risk characteristics of the decommissioning process and the open, public milieu in which it is implemented. Whereas safety culture for operating a nuclear facility has primarily been an intra-organizational matter that aims at preventing a sudden catastrophe, safety culture for the decommissioning process should aim at preventing smaller scale accidents and excessive harmful exposure both during the decommissioning process and long after its completion. This adaptation would meet a particularly important need by motivating members of the decommissioning process management team, a new and untested group, to more carefully address post-transfer risks that may arise long after the organization and their jobs have been terminated.

Adaptation of the safety culture concept would also involve expanding it to encompass both intra-organizational factors and extra-organizational considerations relevant to safety, such as the organization's relationships with numerous regulators, citizens' groups, and other external parties. It would also address the need to cure dysfunctional relationships. This adaptation would be highly valuable, because the plant owner and plant officials involved with an organization going through a decommissioning process previously were concerned with operating the facility according to technical rules and had little need to deal with external parties other than the licensing agency. Therefore, they lacked useful experience for dealing with the social dimensions of the decommissioning process.

The promotion of a safety culture for the decommissioning process by industry, professional associations, and agencies would encourage the adoption of this concept by owners and the organizations they create to implement decommissioning processes. Adaptation and adoption of the safety culture concept has the potential to ensure that the new organization created to manage a decommissioning process—a loose coalition of plant officials, consultants, and cleanup contractors—will quickly coalesce into a socially responsible entity that vigilantly and effectively protects our health, safety, and environment.

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PART TWO

The Search for Analytic Tools

INTRODUCTION

The set of four chapters in Part Two deals with the second main theme of this volume: the search for new diagnostic instruments. Sakuda, Fukui, Yoshida, and Yoshiyama report results of a large study of nuclear power plant technical engineers. Among others, the study draws heavily on work by the famous late Japanese social psychologist Misumi and investigates the factors which influence the safety climate in nuclear operations. Causal modeling was used to link the internal organizational environment to personal safety activities, an approach which facilitates drawing valid conclusions about safety promotion activities.

In the subsequent Chapter 5, Takano, Tsuge, Hasegawa, and Hirose describe results from a questionnaire survey—the CRIEPI Safety Assessment System—in 14 Japanese industrial installations where they investigated possibilities to assess safety dimensions of plant personnel, management, and organizational climate/culture. The model is based on an hierarchical structuring of organizational factors leading up to a plant's safety performance which can be represented by a single safety indicator. Thus, the results lend credibility to the authors' claims that the assessment system may fruitfully be used for bench-marking purposes.

The ASCOT-Guideline-based "Safety Culture Evaluation Support Tool (SCEST)" served as the investigative instrument for Chapter 6 by Makino, Sakaue, and Inoue. Their study tested the appropriateness and practicality of SCEST in seven plants. The tool may be described as an instrument which facilitates self-assessment as well as social assessment of three levels: managers, supervisors, and workers. Gaps between the three levels may be taken as indicators of weaknesses within the organization which need to be corrected in the interest of improving safety culture.

After three chapters by Japanese authors, Chapter 7 by Hsu and Lee addresses the safety climate in Taiwanese nuclear power plants. Their survey study is based on local safety climate issues and covered a group of managers and a group of workers. While both groups show that they experience a positive safety climate in their companies, the gaps between workers and management (management values being higher) provide hints to improve the respective climates.

CHAPTER 4
SAFETY CLIMATE AT NUCLEAR POWER PLANTS IN JAPAN: RECENT FINDINGS

Hiroshi Sakuda, Hirokazu Fukui, Michio Yoshida, and Naohiro Yoshiyama

The purpose of this study was to develop safety climate rating scales and to clarify the characteristics of safety climate at nuclear power plants. Safety climate was defined as an organizational environment that leads members of an organization to give careful consideration to safety and to work in a safe manner. In Study 1, 847 technical engineers working at nuclear power plants of the Kansai Electric Power Co., Inc., were asked to complete questionnaires. Factor analysis extracted five factors that were valid for safety climate rating scales. In Study 2, the data were analyzed with covariance structure analysis, and the fitness of causal models hypothesized in Study 1 was examined. In addition, the characteristics of safety climate at nuclear power plants were identified. These results revealed that a committed attitude among supervisors toward safety and safety education in the workplace, focusing on the clarity of tasks, contributed to the growth of safety climate.

INTRODUCTION

Use of the term "safety culture" has become widespread in the nuclear industry in recent years. The International Atomic Energy Agency (IAEA) proposed this concept in response to the nuclear power plant disaster in Chernobyl in April of 1986. The IAEA defines the concept as a combination of collective and individual characteristics and attitudes that identify safety in a nuclear power plant as a top priority; this approach is based on organizational and individual awareness of the importance of safety (International Nuclear Safety Advisory Group [INSAG], 1991). The agency has also presented the general characteristics of safety culture as well as scales for rating them over a wide range of levels, from governmental to individual (INSAG, 1991; IAEA, 1996). The introduction of this notion is quite significant in that it has led the nuclear industry, which previously had been preoccupied principally with improving the reliability of equipment and facilities, to recognize in a fresh light the importance of organizations and the individuals operating them.

It should be noted that the word "climate" can be used in the same context as culture. The word "climate" connotes human perception of the natural environment, whereas the word "culture" may be used to refer to what human beings have constructed for their existence within a climate. It can be said that culture represents the process in which human beings live in a natural environment and formulate modes of living that are suitably attuned to it. Human life always occupies a place between nature and culture. Thus, human activities that are in discord with the natural environment eventually die out, whereas a culture that is in harmony with the climate will develop. Taking the above points into consideration, we can hypothetically state that a causal relationship exists between climate and culture; in other words, a relationship exists in which climate exerts an influence on culture.

It is therefore quite natural to propose the term “safety climate” in connection with “safety culture.” A nuclear power plant, albeit under organizational management, is, in fact, directly run by individuals within an organization. Obviously, individual actions are closely related to the safety of the nuclear power plant. It can therefore be argued that the prevention of incidents and accidents derived from human factors is, in the final analysis, possible through the solidification of individual safety considerations and actions, which presumably are deduced from the organizational environment. In the present study such an environment is called a “safety climate,” denoting the environment of an organization that promotes safety considerations and suitable actions among its individual members (Fukui, 2001). Whereas the concept of safety culture encompasses organizational and individual characteristics, the concept of safety climate is focused more on the organizational environment that constitutes the basis for actions than on the individuals themselves. It is necessary to incorporate this new concept of safety climate in order to develop a full safety culture.

OBJECTIVES

Often, an organization’s safety promotion activities are not favorably accepted by its constituent members, leading to a loss of initiative and momentum for the activities. It is thought that one reason for this phenomenon is that safety promotion activities are often introduced before managers reach a full understanding of the possible consequences of individual safety actions and the effectiveness of related safety measures.

It is extremely important that those managing an organization have a good understanding of the characteristics of their organization’s safety climate and that they conduct effective safety promotion activities accordingly. Therefore, the objectives of the present study are first to clarify safety climate rating scales and then to identify safety climate characteristics.

STUDY 1: SAFETY CLIMATE RATING SCALES

Methodology

The safety climate of nuclear power plants was examined through the use of a written questionnaire survey conducted among all technical employees in positions below section chief at three of the nuclear power plants of the Kansai Electric Power Co., Inc. The questionnaire included 20 of the workplace-morale survey items identified by the Japan Institute for Group Dynamics (Misumi, 1984), 15 of the safety-awareness survey items created by the Institute of Nuclear Safety System, Inc., and the Japan Institute for Group Dynamics (Misumi et al., 1996), 22 safety-culture-index survey items selected from the Assessment of Safety Culture in Organizations Team (ASCOT) guidelines (IAEA, 1996), and 20 safety-action survey items drawn up from analyses of occupational hazard incidents that occurred at the three power plants. These items can be divided mainly into two types: those concerning safety measures taken by individuals and those concerning safety measures taken by the organization or workplace to which the individuals belong. Furthermore, with the exception of the workplace-morale survey items, there is a pairing of questions that ask about the importance of the content with questions that ask about how the contents are currently being put into practice. All items were rated on a five-point scale. The survey was carried out between October 1999 and January 2000.

The analysis of the study covered the survey items on safety awareness, safety culture, and safety actions, that is, all items other than those on workplace morale. The perceived importance of the questionnaire topics were excluded from the analysis because, although their appropriateness was justifiable, most scores for these items were high, at 4 or above, with little fluctuation (Fukui, Yoshida, & Yamaura, 2000). The total number of question items about the current state of questionnaire topics amounted to 57. The analysis was focused on employees of the operation and maintenance sections, who are closely involved in on-site tasks. After inappropriately filled questionnaire sheets were discarded, the total number of respondents included in the analysis was 847 employees from three power plants.

Analysis was conducted in the following manner. Factor analysis was performed on the scores of question items in order to select five representative items for each factor; the total sum of scores of the five items was adopted as the score for each factor. Next, using the definition of safety climate as a basis, we studied the correlation between the scores of factors related to safety actions by individuals and those related to the organizational environment. This process enabled us to gauge the legitimacy of safety climate rating scales, which were adopted as such when their legitimacy could be verified.

Results

Fifty-seven items were subjected to principal factor analysis. For this analysis the communality of correlation matrix diagonal components was estimated through use of the squared multiple correlation method, and the five-factor solution was adopted in accordance with the “scree” criteria. For rating, five items with a factor loading of 0.4 or above and with content that was different from the others were selected for each factor. We did not select question items that had high rating scores and a small standard deviation because they pose no problems in terms of safety climate and because their data contribute little to the explanation of any relationship among the factors. The Appendix at the end of this chapter gives the results of the second five-factor analysis of the five items selected for each factor (thus, 25 items in total); it was conducted in the same manner as the first factor analysis.

Although the order of factors changed, the items belonging to each factor were the same as in the first analysis. Using the contents of the classified items as a basis, we named the factors “confidence in knowledge and skills (Factor I),” “manager’s/supervisor’s attitude (Factor II),” “workplace safety education (Factor III),” “clarity of tasks (Factor IV),” and “personal safety action (Factor V).” Cronbach’s coefficient (alpha), an indicator of the reliability of the rating scale of each factor, ranged from 0.788 to 0.846; therefore, the reliability of the rating scales was considered proven. The factors “confidence in knowledge and skills” and “personal safety action” concerned the evaluation of individuals, and the factors “manager’s/supervisor’s attitude,” “workplace safety education,” and “clarity of tasks” were related to the environment of the organization to which the individuals belonged.

Figure 4.1 shows the rating scores of the factors. Because the rating score of each factor is the total sum of scores of the five items, the lowest score is 5 points and the highest score is 25 points. It should be noted that the scores are generally comparable, although the rating scores of “workplace safety education” and “confidence in knowledge and skills” are slightly lower.

These results support the hypothesis that, among the constituents of safety climate, a proportional correlation exists between the factors most closely related to individual safety considerations and actions (i.e., “personal safety action” and “confidence in knowledge and skills”) and the organizational environmental factors (i.e., “manager’s/supervisor’s attitude,” “workplace safety education,” and “clarity of tasks”).

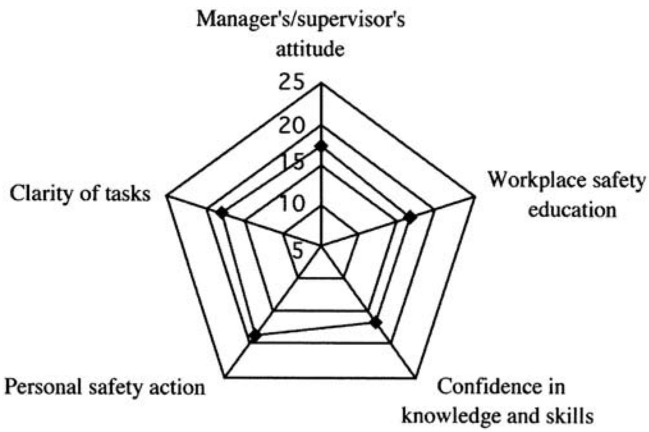

Figure 4.1 Scores for each factor, with average of total sum of the five items per factor (N=847).

Table 4.1 indicates the correlation coefficients of the rating scales for each factor. The correlation coefficients of "personal safety action" with "manager's/supervisor's attitude," "workplace safety education," and "clarity of tasks" ranged from 0.47 to 0.49. The correlation coefficients of "confidence in knowledge and skills" with "manager's/ supervisor's attitude," "workplace safety education," and "clarity of tasks" ranged from 0.30 to 0.35, which is slightly lower than those of "personal safety action."

Table 4.1 Correlation of rating scales for each factor

Confidence in knowledge and skills	1.00				
Manager's/supervisor's attitude	0.30	1.00			
Workplace safety education	0.33	0.58	1.00		
Clarity of tasks	0.35	0.65	0.61	1.00	
Personnel safety action	0.48	0.49	0.47	0.49	1.00

p<.01 (two-tailed test), if r>.088.

Observations

A proportional correlation between the organizational environmental factors ("manager's/supervisor's attitude," "workplace safety education," and "clarity of tasks") and each of the rating groups of the individual factors ("personal safety action" and "confidence in knowledge and skills") is thus demonstrated. Accordingly, it is deemed possible to predict the degree of "personal safety action" and "confidence in knowledge and skills" by gauging the ratings of the organizational environmental factors. This means that the three organizational environmental factors can be adopted as safety climate rating scales.

Meanwhile, a proportional correlation between the individual factors "personal safety action" and "confidence in knowledge and skills" was also found. It is possible to interpret this correlation, in part, as a manifestation of the influence of the organizational environmental factors on the factor "personal safety action" via the factor "confidence in knowledge and skills."

STUDY 2: SAFETY CLIMATE CHARACTERISTICS

Methodology

Using the concept of safety climate discussed above as a basis, we presumed that characteristics of the safety climate of nuclear power plants could be analyzed with a causal model of individual safety actions, with the organizational environmental factors serving as the causes in the model. To examine the causal model of individual safety actions, factors identified in the factor analysis were studied as constituents of the model. That is, the factor "personal safety action" was considered to be the constituent closest to the current state of individual safety actions among the factors identified in the factor analysis. Therefore, the causal model was constructed with "personal safety action" as the result and the other factors as its forecasting elements.

Examination and analysis were conducted in the following manner. First, the nature of influence was studied between each of the two factors relevant to individual safety actions—"personal safety action" and "confidence in knowledge and skills" —and the organizational environmental factors, "manager's/supervisor's attitude," "workplace safety education," and "clarity of tasks." Next, the link of influence between the factors "personal safety action" and "confidence in knowledge and skills" was examined. Finally, the results were comprehensively examined in order to study the overall influence between "personal safety action" and the other factors. To analyze influence, a causal model was set up for each case, and the legitimacy of each causal model was evaluated through covariance structure analysis. In other words, causal models were constructed with the factors identified through factor analysis serving as latent variables and the items belonging to each factor serving as its observational variables.

RESULTS

Figure 4.2 shows the path diagram of the causal model and the standardization solution of analysis results. With "personal safety action" as the standard variant, a path of influence from "manager's/supervisor's attitude" to "personal safety action" via "workplace safety education" and a path of direct influence from "manager's/supervisor's attitude" to "personal safety action" were assumed. Paths of influence from "clarity of tasks" to "personal safety action" via "workplace safety education" and from "clarity of tasks" to "personal safety action" via "confidence in knowledge and skills" were also set up. The factors "manager's/supervisor's attitude" and "clarity of tasks" were judged to be related, but the nature of their link was found to have no influence for the following reason. Although the two factors do represent two aspects to which managers and supervisors should give consideration, "clarity of tasks" is related to improvement in the content of training, which can be carried out in the workplace and external training facilities. Therefore, it is possible to assume the presence of influencing elements that are common to the two factors and that can account for the high point ratings of the two, but no reason positively points to a direct link of influence between the two.

With respect to observational variables, the following hypotheses were set forth for analysis. A correlation between error variables, hereafter referred to as an error correlation, was assumed to exist between the observational variables q32_1, "the higher echelons of the power plant discuss safety issues," and q32_2, "the higher echelons recognize and approve personnel's safety-oriented attitudes and efforts." This assumption was made because safety-oriented attitudes and efforts are probably covered in the higher echelons' discussions, which may lead to some of the personnel feeling recognized.

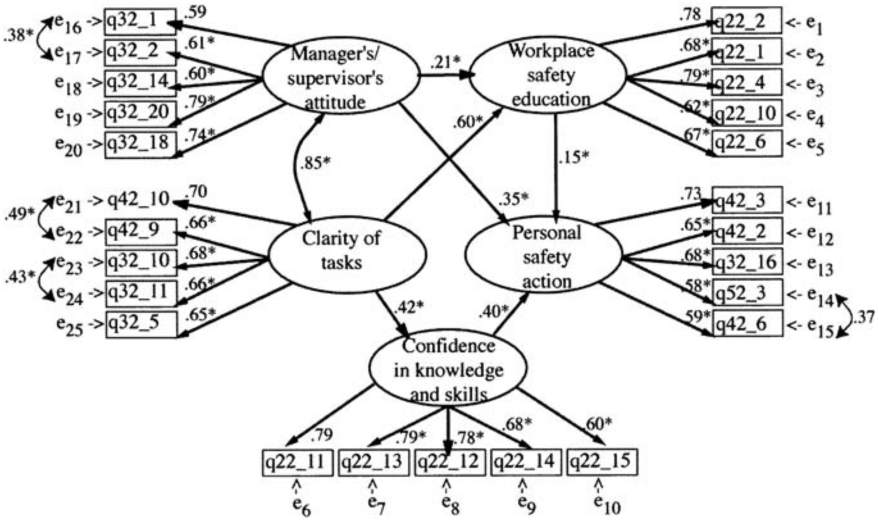

Figure 4.2 Causal model and the standardization solution of analysis results. Adjusted goodness of fit index (AGFI)=. 921; root mean square error of approximation (RMSEA)=.044; e=error variable; *p<.05 (level of significance).

An error correlation was also assumed between q42_9, "in the workplace, the scope and methods of tasks are clearly indicated," and q42_10, "in the workplace, the contents and methods of tasks are explained," because it was deemed highly possible that respondents recognized the importance of clarity of indications and explanations for a good understanding of tasks through similar experiences.

An error correlation was assumed to exist between q32_10, "in safety-related training, the reasons for tasks and operations are explained," and q32_11, "in training, issues and questions posed are given due consideration," because it was assumed that a large number of the respondents answered these questions while recalling the same training programs and the same trainers.

An error correlation was also set up between q52_3, "you report to your superior even minor problems and incidents," and q42_6, "you report accurately anything that seems dangerous in the workplace," because it was assumed that the respondents answered these questions while recalling the same person to whom they should report, although the phenomena concerned could vary to a certain extent.

Covariance structure analysis was conducted under these conditions. The standardization solutions of analysis results are as follows. The influence of "manager's/supervisor's attitude" on "personal safety action" was exercised via "workplace safety education" (.21, .15) and through a direct path (.35). The influence of "clarity of tasks" on "personal safety action" was exercised via "workplace safety education" (. 60, .15) and "confidence in knowledge and skills" (.42, .40).

Observations

The factor "manager's/supervisor's attitude" influences "personal safety action," both directly and via "workplace safety education." The factor's direct influence on "personal safety action" is especially important. When compared with the influence of "clarity of tasks" on "personal safety action" via the mediating factors "workplace safety education" and "confidence in knowledge and skills," "manager's/ supervisor's attitude" seems to be the most influential factor in the organizational environment.

The factor “workplace safety education” is influenced more strongly by “clarity of tasks” than by “manager’s/supervisor’s attitude.” Although it is possible to interpret “workplace safety education” as a constituent factor representing the workplace atmosphere, it seems that workplace safety education is influenced more strongly by concrete actions, such as explanation of tasks, instructions, and responsiveness to personnel’s questions to ensure their understanding, than merely by managers’ and supervisors’ attitudes toward safety.

In the analysis of rating scales, the scores are low for the mediating factors “workplace safety education” and “confidence in knowledge and skills.” The strongest influence on these mediating factors comes from “clarity of tasks.” Therefore, it is believed that activities with a greater emphasis on “clarity of tasks” will be required in the future.

The influence of “workplace safety education” on “personal safety action” is not strong. Nevertheless, it is assumed that workplace safety education plays an important role in information-sharing. Information provided to personnel during workplace safety education becomes part of their knowledge, serving as the basis for their decision-making about individual safety actions. In addition, as a mediating factor, “workplace safety education” is influenced particularly strongly by “clarity of tasks” and in turn influences “personal safety action.” Therefore, “workplace safety education” constitutes an essential influential factor that cannot be overlooked.

CONCLUSION

An examination of the causal model of “personal safety action” leads to the conclusion that the individual action of “personal safety action” is based on “confidence in knowledge and skills” and is supported by “manager’s/supervisor’s attitude” and “clarity of tasks.” Moreover, “workplace safety education” indicates the state of a workplace’s engagement with and commitment to safety activity and plays an important role as a mediating factor that promotes information-sharing. The factors “workplace safety education” and “confidence in knowledge and skills” can be enhanced through efforts on the part of managers and supervisors to achieve “clarity of tasks” when trying to support personnel’s understanding.

From the above points it can be concluded that the factors of the organizational environment —“manager’s/supervisor’s attitude,” “clarity of tasks,” and “workp lace s education” —influence the safety actions of individuals and are important constituent factors of a safety climate. The examination results of the causal model of “personal safety action” support the results of the examination of safety climate rating scales in Study 1. Hence, it can be inferred that “manager’s/supervisor’s attitude” and “clarity of tasks,” which are located “upstream” of “personal safety action,” should be emphasized in workplace safety education as organizational safety promotion activities.

In this chapter we have focused on the cause-and-effect relationship between personal safety actions and the organizational environment. All the individuals belonging to an organization engage in work and take actions in a unique atmosphere generated by the organization itself. Therefore, personal action is always influenced by the atmosphere of the organization, that is, the organization’s environmental factors. Some of these may be good and some may be bad. An organization generally has a pyramid-shaped class structure. The top echelons of the organizational strata make a disproportionately large contribution to building and shaping an organization’s climate.

It sometimes happens that an organization’s policy toward safety is not readily accepted by its constituent members or that workers’ safety actions become routine or less frequent and less thorough. Such phenomena seem in part to be the result of people at the top of the organization drafting activity policies without fully understanding the characteristics of the organization or the state of the workplace.

Alternatively, these people may not be making any effort to help the organization's members fully understand the adopted policy. For those who operate and manage the organization, it is extremely important both to clearly appreciate the causal relationship between the organization's characteristics and safety actions and to implement safety action more effectively. Although it is important for those at the top of the organization to continually tell members of the organization to take safety actions, those at the top should first create an atmosphere in which safety actions are comparatively easier to undertake, as well as make efforts to improve the organizational environment for those working beneath them.

PROPOSALS FOR THE IMPLEMENTATION OF SAFETY PROMOTION ACTIVITIES

In carrying out the present research we had the opportunity to discuss with nuclear power plant personnel the safety promotion activities carried out in their workplace. Some important points drawn from these discussions, particularly in terms of the factors constituting a safety climate, are summarized below in the form of concrete proposals.

Proposals related to "manager's/supervisor's attitude"

A manager or supervisor should show active interest. Subordinates cannot be seriously motivated to pursue an objective for which their superior does not show much enthusiasm. Conversely, a superior's active interest can stimulate subordinates' involvement.

Explanations and instructions about tasks should be given with reference to safety. When task explanations and instructions are given in such a way as to emphasize only efficiency, personnel tend to aim for efficiency rather than safety, forgetting that in their workplace safety comes first. In order to indicate the degree of importance that management attaches to safety, explanations and instructions should be given with reference to safety.

Safety activities should be carried out with perseverance and continuity. Safety activities can reach a peak and then gradually die down. Managers and supervisors should show by their actions that they continue to pay close attention to safety activities.

The safety efforts of personnel should be evaluated on a small scale, daily, even through daily conversations, without considerations or great efforts of formality. Evaluation tends to be associated with major achievements, such as those assessed in an official compensation system. In a workplace where safety is the prerequisite, safety activities rarely stand out as achievements. It is therefore unusual for personnel to feel rewarded for their safety activities or to make an issue of them. In view of this situation, small, daily safety activities should be evaluated through daily communications with the personnel, without considerations of formality.

Proposals related to "clarity of tasks"

When safety promotion activities are carried out, their relevance to actual tasks should be emphasized. Activities whose principles deviate from actual tasks tend to look like somebody else's affair. Because members of a workplace engage in different tasks, activities should be carried out in such a way as to underline their relevance to actual tasks and their objectives, without emphasizing too much the form of activities.

The objectives, planning, and contents of safety promotion activities should be concrete enough to facilitate the visualization of actions to be taken. In order for those working on the work site to take actions in accordance with the organization's principles, they should be able to visualize concrete actions to be taken as part of their tasks.

Excessive or overdemanding planning or action programs should be avoided. People can be conscious of only a limited number of safety precautions at one time; these precautions are mostly related directly to their tasks. From the standpoint of managers and supervisors, all safety precautions are important, whereas personnel on the work site may view them strictly in relation to their tasks. Personnel should be encouraged to focus on activities that are particularly important in relation to their tasks.

Explanation of the background to, reasons for, and necessity of activities should be provided. People cannot be motivated to achieve objectives of which they are not convinced. Maximum efforts should be made to obtain the personnel's understanding of even the smallest detail, so that personnel do not perceive activity principles as simply something imposed on them.

Proposals related to "workplace safety education"

Activities should be planned for the smallest possible unit of implementation. In order to enable personnel to engage in safety activities as their own affair, it is essential that activities be related to actual tasks and planned and implemented by small groups comprised of members whose tasks are similar, rather than by the entire workplace unit. This approach is important also from the standpoint of revitalizing the workplace.

Opportunities to reflect on safety activities should be provided. Instructions and communication of information do not always suffice to explain the necessity of safety activities. It is therefore necessary that individuals take time to reflect on safety activities and convince themselves of their importance. Discussions should be encouraged in order to provide such opportunities.

SUMMARY

At the outset of this research, the notion of safety climate was not firmly established. The concept of safety culture and its development continue to impose a weighty proposition. However, once the supposition that the organization determines its constituent members' actions was put forth, the orientation of the research was clarified, with an organization and its constituent members clearly separated. In addition, nuances of the Japanese language suggest that the term *anzen fudo* (safety climate) is more appropriate than *anzen bunka* (safety culture) when examining safety from a causal standpoint. All of these points lead to the conclusion that the development of a safety culture requires the incorporation of the concept of safety climate.

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No.	Item summary	Factor 1	Factor 2	Factor 3	Factor 4
q22_11	You have knowledge and skills required for your present post.	.820	.033	-.065	-.006
q22_13	You are confident that you will calmly deal with eventualities.	.777	-.051	.034	-.079
q22_12	You have knowledge and skills necessary to ensure safety.	.746	.015	.019	-.014
q22_14	You can adapt yourself to facility and equipment advances.	.624	-.007	-.007	.042
q22_15	You know the content of tasks carried out by your colleagues.	.523	.000	.069	.146
q32_1	The higher echelons of the power plant discuss safety issues.	.014	.708	.005	-.082
q32_2	The higher echelons approve personnel's safety-oriented attitudes and efforts.	-.015	.704	.020	-.035
q32_14	The higher echelons of the power plant visit the work site for careful observation.	.026	.572	-.073	.084
q32_18	Your superior makes efforts so that those contributing to safety will be recognized.	-.048	.493	.096	.151
q32_20	Your superior pays attention to the working environment.	-.012	.481	.121	.261
q22_2	The workplace has an ambiance that encourages discussions on safety.	.017	.049	.755	-.041
q22_1	In the workplace, you discuss "near-miss" episodes.	-.016	-.118	.748	.038
q22_4	You discuss accidents and safety issues in an open and frank manner.	.075	.035	.718	.073
q22_10	In the workplace, ideas for improvements are actively proposed.	-.057	.168	.469	-.017
q22_6	Opinions and ideas are put to active use to ensure safety.	-.024	.244	.438	.038
q42_9	In the workplace, the scope and methods of tasks are clearly indicated.	-.017	-.071	-.035	.768
q42_10	In the workplace, the contents and methods of tasks are explained.	-.018	-.020	.012	.766
q32_10	In safety-related training, the reasons for tasks and operations are explained.	.047	.205	.119	.513
q32_11	In training, issues and questions posed are given due consideration.	.032	.219	.094	.496
q32_5	Who is responsible for which task in the workplace is clear.	.041	.276	.054	.393
q42_3	You verify the safety of efficient working methods before implementation.	.022	.046	-.003	-.010
q42_2	You check in advance to see if any danger exists in the work area.	.049	.047	.005	-.078

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Appendix

Factor pattern of 25 question items selected through principal factor analysis

CHAPTER 5
DEVELOPMENT OF A SAFETY ASSESSMENT SYSTEM FOR PROMOTING A SAFE ORGANIZATIONAL CLIMATE AND CULTURE

Ken-ichi Takano, Tadashi Tsuge, Naoko Hasegawa, and Ayako Hirose

The Central Research Institute of Electric Power Industry (CRIEPI) is developing a safety assessment system to investigate and measure the safety level of industrial factories and plants through the use of a questionnaire survey. This chapter describes the applicability and feasibility of the proposed system by examining the results from an intensive questionnaire survey conducted among 14 Japanese plants. This questionnaire involves 122 items classified into three categories: (a) safety awareness and behavior of plant personnel, (b) safety management, and (c) organizational climate and culture. The results verify the anticipated functions: (a) a comprehensive indicator can be calculated to express total safety status; (b) directions and instructions can then be proposed to prevent labor accidents and facility failures; (c) a safety profile can show the status of several important safety indicators within a factory or plant, thereby enabling actions to be taken for further ensuring safety.

INTRODUCTION

Several organizational accidents in various industries have occurred in Japan, such as the JCO criticality accident, the food poisoning accident at Snow Brand Milk Products Co., and the case of Mitsubishi Motor Co. deliberately concealing recall data for long periods. It seems these cases basically arose from organizational flaws and managerial problems. Although the accidents were triggered by unsafe actions, incorrect behavior, or human errors, these triggers were themselves made possible through the gradual weakening of the protective barriers put in place by the organization's management, imperfect and ineffective monitoring systems, and an unfavorable workplace climate (Reason, 1997; Sasou et al, 1999; Takano, 2000).

These cases have shown that Japanese organizations must learn lessons from organizational accidents. These accidents were found to have several common factors, such as harsh business conditions, habitual violation of rules and procedures, facility shortcomings, constant time pressures, inadequate checks of the conditions, inappropriate feedback on past experiences of success, defensive attitude of employees, and inadequate communication. Frequent organizational accidents prompted industries to take action to ensure safety culture within organizations. With the sudden JCO accident acting as a catalyst, Japanese nuclear industries established the Nuclear Safety Network, which aims to promote mutual information exchange between nuclear power companies, nuclear fuel companies, and nuclear system venders, in order to share good practices, experiences about operations, and information about incidents. Yet it is also necessary to monitor levels of safety culture and to connect the results of this monitoring to practical and effective approaches to ensuring safety culture in organizations and maintaining it at a higher level.

Although safety culture issues could be regarded as an ideal subject for gleaning important organizational factors that influence safety performance, it was first in the 1980s that several studies began to investigate the relationship between safety performance, organizational culture, safety management, and workers' safety awareness and behavior. Zohar (1980) conducted a survey on safety awareness among workers in the food-processing, chemical, and textile industries. In the questionnaire they identified crucial factors for safety, such as training in safety issues, time pressures, the position of staffs responsible for safety, and the commitment of top management. Diaz and Cabrera (1997) carried out an intensive survey among airline ground staff on the relationship between attitudes toward safety and organizational climate. They found a significant regression between workers' attitudes toward safety and organizational safety policy, productivity, and upper management's commitment to safety.

Haber et al. (1992) have continued their efforts within the nuclear power industry to develop a methodology that can be applied to actual sites in order to identify relations between safety performance and organizational factors. They adopted several practical methods of investigation: functional analyses by walk-through and talk-through, observation of employee behavior, and a questionnaire on employees' attitudes toward safety. They were able to identify five key factors: communication, standardization of work, decision-making and problem-solving, management and supervision, and organizational culture.

The above-mentioned studies suggested to us that there might be several controllable organizational factors that promote safety culture in organizations. Moreover, we thought it would be interesting to examine whether such controllable organizational factors were largely the same as the factors identified above and the factors involved in recent accidents in organizations.

With respect to these questions, the Central Research Institute of Electric Power Industry (CRIEPI) has been conducting questionnaire surveys for a variety of industries over the last five years, including the construction industry, the chemical/textile industry, and the manufacturing industry. We found that organizational factors definitely influence employees' safety awareness and the group's safety activities (Hirose et al., 2000; Hirose et al, 2001; Kojima et al., 2000; Kojima et al., 2000). In addition, these surveys revealed crucial implications, such as the importance of participatory safety activities, active communication throughout the hierarchy as well as between colleagues, commitment of top management, and motivation to maintain safety. Such important issues were also pointed out by a parallel investigation of representative "safe companies."

In consideration of the above findings, CRIEPI initiated a project to develop the CRIEPI Safety Assessment System (CSAS), which can measure and evaluate the safety level of organizations, such as factories and plants, in order to find suitable corrective measures to cover weaknesses in the previous safety approach. The development of CSAS is only a first step to improvements of organizational safety climate and culture. Following the development described above, a Safety Proposal System will be created; this system will offer effective and pragmatic improvement proposals for each factory or plant based on an assessment of the obtained results. In this chapter the intended functions of the safety assessment system are evaluated on the basis of survey results from 14 plants within the nuclear power industry. We then discuss the applicability and feasibility of this system.

METHODS

Questionnaire survey participants

Workers in a specific plant can be classified roughly into one of two occupational areas: office workers and engineers. Because the main purpose of this study is to ensure safety-oriented behavior in technical areas, only engineers who directly or indirectly work with mechanical facilities in the plant participated in the survey. The occupations were broken down into five categories: operations, maintenance, general engineering, health physics engineering, and chemical engineering. Because the content and contract arrangement of maintenance work are very similar to that of the construction industry, and because the range of tasks of operations staff is much the same as that for workers in the chemical industry, we used the results from the questionnaire surveys to make comparisons between operators and chemical-industry employees as well as between maintenance workers and construction workers. In order to reflect the total number of employees in each occupation, the number of operators and maintenance workers participating in the survey was relatively larger than the numbers for other occupations. For each plant, about 60 workers were chosen to participate in the survey (see Table 5.1).

Table 5.1 Breakdown of CRIEPI questionnaire survey participants in each plant, by occupation

Occupation	**Section manager/ assistant manager**	**Supervisory staff**	**Total**
Operations	6	15	21
Maintenance	6	15	21
General engineer	3	3	6
Health physics engineer	3	6	6
Chemical engineer	3	6	6
Total	21	45	66

Questionnaire format

Conception and structure of organizational factors

It would be difficult to quantitatively evaluate a safety indicator; moreover, it would also be quite problematic to understand the conception and structure of organizational factors and identifying components separately according to each category. Each organizational factor is not independent but, rather, interrelated with one another. Thus, researchers have adopted a relatively simple model of organizational factors, proposed by Taniguchi et al. (1995) and Watanabe (1996). This model has a hierarchical structure of five levels, with safety performance at the very top of the hierarchy (see Figure 5.1). The crucial point of this model is to show that managers can easily make commitments promoting safety in the form of daily activities through the third level, “management,” which also includes general management. The factors involved in the third level are the only controllable organizational factors, unlike the factors for Levels 0, 1, 2, and 4, where it is usually difficult to make direct commitments.

The questionnaire was designed according to this model. When writing the actual questionnaire, we referred to various safety questionnaires, such as the International Atomic Energy Agency (IAEA) guidelines and the format used by the railway industry for evaluation of safety attitudes (see Takano et al., 2001, for more details). Once the basic questionnaire was completed, three revisions of it were made based on pilot studies in the construction, chemical, and manufacturing industries.

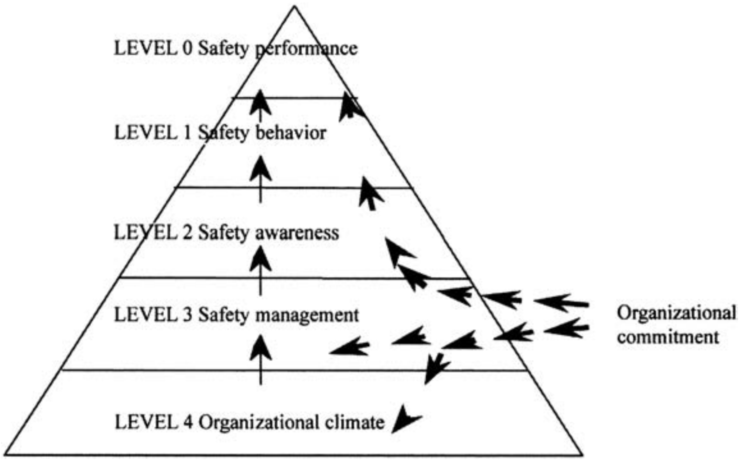

Figure 5.1 Structure of organizational factors, with safety performance at the top of the hierarchy. Adapted from Management Culture for Safe and Reliable Operation of Nuclear Power Plants in Japan, by T.Taniguchi, Y.Tomioka, M.Echizen, T.Enomoto, and S.Kondo, 1995, *Proceedings of the International Topical Meeting on Safety Culture in Nuclear Installations, ANS & NEA,* Vienna, 551–560.

Structure of the questionnaires

This tailored questionnaire format included 124 questions on rates of labor accidents (RLA) and rates of facility failures (RFF; Level 0), the individual's safety awareness and behavior (Levels 1,2), safety management (Level 3), and organizational climate and culture (Level 4). Additionally, the following items w ere also included among the questionnaire items on organizational climate and culture: items for evaluating organizational climate proposed by Litwin and Stringer (1968); items derived from the organizational profile by Likert (1959); and items used in the management culture survey presented by Taniguchi et al. (1995), for safety issues that have been recognized in previous studies as being closely related to general organizational issues (Hirose et al., 2000, 2001). Table 5.2 provides a summary of the items in each of the categories: safety performance, workers' safety awareness and behavior, safety management, and organizational climate and culture.

Table 5.2 Summary of questionnaire items in four main categories

Category	Number of items	Summary of items
Safety performance (Level 0)	2	Rate of labor accidents, rate of facility failures
Worker's safety awareness and behavior (Levels 1 and 2)	43	Pride taken in own job and motivation, Inclination to work, proactive checks of the conditions and active attitude toward safety, compliance with rules and instructions, disposition to place more importance on safety than on schedule
Safety management (Level 3)	29	Strict rule adherence, clarification of unsafe acts and safe acts, safety education and training rich in content, active handling of emergent risks and practical use of information obtained, active reduction of potential risks and

Category	Number of items	Summary of items
		preventive use of information obtained, implementation of system and incentives to stimulate various safety activities, systems and interchange for safety management and activities
Organizational climate and culture (Level 4)	50	Improvement of workplace environment, conservative organizational climate, mutual cooperation and human relation among workers, trust and reliance between managers and employees as well as among employees, motivation of employees through proper role- and task-sharing, upper management's attitude to promotion of safety

Implementation

The questionnaire survey was conducted in March 2001 once approval was received from the industry's Human Factors Committee. In most cases, the distribution of the questionnaires was carried out by the representatives of the 14 plants. In some cases, all of the questionnaires were sent all at once to a committee member, and then he sent it on to the representative of the respective plant. After the plant personnel listed in Table 5.1 filled in the questionnaires, each individual participant sealed up his or her envelope and returned it to the plant representative, who sent it back to CRIEPI. The response rate was 97.0%, and an effective reply was 95.6%.

Analysis

The first two questionnaire items (see Level 0 in Table 5.2) address employee performance; as a result, these two items were excluded from the analyses. The number of items was reduced, therefore, from 124 to 122. The following analyses were made:

1. An average score and a standard deviation of all plants (total average) for each questionnaire item were calculated.
2. An average score and a standard deviation of each plant (site average) for each item were calculated.
3. Tests for a significance difference (using a t-test) between each site average and the total average were carried out.
4. A plant safety profile for all items was obtained.
5. The total average was compared with those of other industries, such as the construction, chemical, and textile industries.
6. A multivariate analysis, which was the principal component analysis, was applied in order to identify a significant indicator of safety levels.
7. A multiple regression analysis was applied between safety performance and each item in order to find significant relationships.

After these analyses were carried out, all questionnaire items in Table 5.2 (excluding the two items under "Safety performance") were divided into a total of 20 groups, in each of which questions with related topics were assembled and named as a common category (see Table 5.3). All questionnaire scores were summed up for each group in order to obtain group scores. The group scores for each plant were standardized with the total group score (average score of all the plants). The standardized group scores for each plant were presented as 20 factors of its safety profile by plotting them on a radar chart.

RESULTS

Test of significant difference between plants

The difference between the total average score and each site average score for each questionnaire item was tested for significance at the 1% and the 5% level by using a t-test. Evaluating the score itself and level of significance, significant questionnaire items were classified into two categories: "superior," meaning "a site average was significantly higher than the total average," or "inferior," meaning "a site average was lower than the total average." Following this process, definite differences between plants could be observed. A plant with relatively more "superior marks" tended to have these superior item scores distributed over the three categories shown in Table 5.3. In no case were both superior and inferior item scores mixed within a single plant. The inclination was toward either "superior-rich plants" or "inferior-rich plants," in part because the questionnaire items are themselves correlated with each other. Previous studies conducted in the construction and chemical industries have shown that workers' awareness, management, and organizational factors are closely related (Hirose et al., 2000, 2001; Kojima et al., 2000a, b). Hence, this correlation seems to be a common feature to organizations in every industry. Testing each questionnaire item for a statistically significant difference between the total average score and each site average score is an effective way to grasp the features of individual plant safety issues.

The questionnaire items with many "superior" and "inferior" scores—that is, items for which a great deal of difference between plants was identified—were schedule and rule compliance issues, coping with hazards, workers' commitment to safety activities, trust between organizational members, and communication issues.

Table 5.3 Classification of questionnaire items according to category and group

Questionnaire categories	Groups of questionnaire items within each category	
Category I: Individual safety awareness and behavior	1.	Pride taken in one's work and motivation
2.	Inclination to carry out one's work	
3.	Proactive check of the conditions and active attitude	
4.	Instruction in and compliance with safety rules	
5.	Active awareness and behavior oriented to maintaining safety	
6.	Disposition to place more importance on safety than on schedule	
Category II: Safety management in the workplace	7.	Strict attitude toward keeping subordinates compliant with rules

Questionnaire categories	Groups of questionnaire items within each category	
8.	Clear definition of safe and unsafe behavior	
9.	Continual enrichment of safety education	
10.	Proper handling of actual risks of incidents and efforts to prevent recurrence	
11.	Proper awareness of and coping with hazards, as well as integration of feedback on such issues into daily activities	
12.	Implementation of and system to continue safety activities	
13.	Structure for and information exchange about safety management and activities	
Category III: Organizational climate and culture in the workplace	14.	Workplace environment kept orderly to enable easy execution of tasks
15.	Conservative organizational climate	
16.	Good cooperation and human relations between team members	
17.	Interdependence and trust between all members in workplace, regardless of social rank	
18.	Taking active communication within and without organization	
19.	Incentives based on proper role-sharing and qualifications	
20.	Commitment of top management	

Comparison with other industries

Because operations tasks in a plant are nearly the same as those in the chemical industry, and because maintenance work in plants is quite similar to that in the construction industry, we decided to compare the total average scores of operations and maintenance with the scores of other industries through the use of a t-test. However, the contents of the questionnaire were not exactly the same; as a result, the number of questionnaire items for comparison were 35 items in Category I, 21 items in Category II, and 20 items in Category III.

Through these comparisons we found that 21 of the total 35 items in Category I, 16 of the total 21 items in Category II, and 13 of the total 20 items in Category III showed a significant difference. This difference is partly due to differences in specific job contents, work structure, experience, company policies or regulatory laws, and so on and not only due to superficial similarities in job contents. These kinds of invisible differences can affect the score of each questionnaire item; thus, the standard value of the total average score for each industry should be prepared separately for each industry.

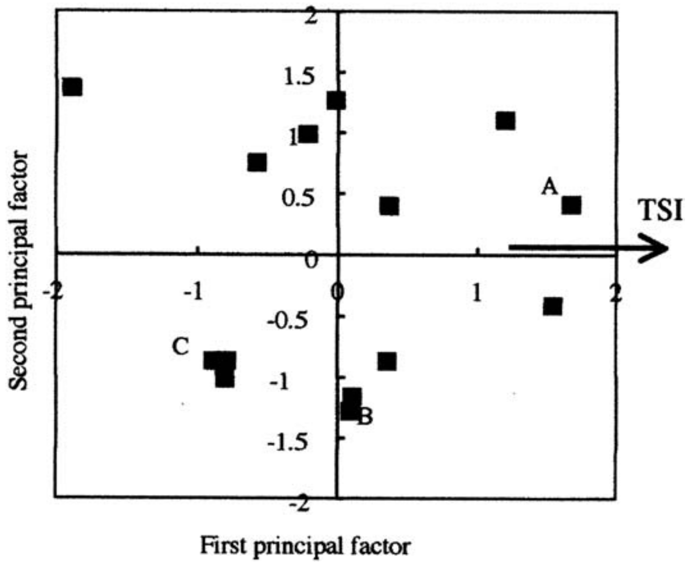

Figure 5.2 Principal factor analysis of questionnaire items; each point represents a specific plant. The first principal factor corresponds to the total safety indicator (TSI).

Relationship between questionnaire items

To find the relationships between questionnaire items, principal component analysis was applied to the site average matrix. The result is shown in Figure 5.2, where the first principal component and second principal component correspond, respectively, to the x-axis and the y-axis. Many of the important safety factors mentioned in the introduction concentrated on the first principal component. The first component in principal component analysis was regarded as an "average factor" that represented the whole trend of analyzed data. Thus, authors considered the first component as representing a comprehensive safety indicator, called a "total safety indicator" (TSI).

The second component—the y-axis in Figure 5.2—was considered to be the axis with a priority on schedules/technique toward the plus side and with a priority on confirmation/ safety toward the minus side. In Figure 5.2, the value of the first component (the TSI) ranged between −2 to +2. The position of each mark ( ) corresponds to each plant and indicates the level of an organization's comprehensive safety.

The subcomponents comprising the first principal component are shown in Table 5.4, with factor loadings. The factor loading is regarded as a contribution factor of each questionnaire item to the first principal component. If the factor loading is positive, the higher value indicates a greater contribution to the first principal component. Conversely, a negative indicates an adverse contribution to it. In Table 5.4, the most significant questionnaire items with a higher factor loading are listed toward the top; underlined items are the ones for which a significant regression was identified with labor accident and facility failure rates. These items were, for the most part, the same crucial factors identified in previous works (Hirose et al., 2000, 2001; Kojima et al., 2000a, b; and in the interviews of employees in the chemical and construction industries (Hasegawa et al., 2000).

Table 5.4 Contents of subcomponents (questionnaire items) comprising the first principal component analysis

	Questionnaire items	Factor loading
Positive factors	Information follow-up and quick feedback on unsafe implications and problems	0.92
	Checks and reviews with effective advice from managers	0.90
	Pragmatic safety education and training relevant to daily activities	0.90
	Good communication between employees and vendor staff within the workplace	0.89
	A pleasant enough atmosphere to facilitate close cooperation among workers	0.88
	Feeling right and gratified in joining the company	0.86
	Choosing safety side by ending a task if feeling dangerous situation	0.86
	Proper role- and job-sharing in carrying out tasks	0.86
	Continuous efforts to discover unsafe aspects and problems in the workplace	0.86
	An understanding of the importance of safety activities for maintaining safety in the workplace	0.86
Negative factors	Majority of managers shifting responsibility to the person concerned when problems occur	–0.85
	Task performance often influenced by unsatisfactory planning	–0.83
	Violations against rules and procedures under time pressures	–0.79
	Desire or predilection to work in a low-risk environment	–0.73
	Young employees with overconfident behavior	–0.70
	Different orders and instructions coming from several supervisors	–0.69
	Communication gap due to age disparities	–0.69
	Feeling ridiculous by being the only one to keep to the rules	–0.68
	Decisions made only by considering organizational convenience, not by considering social circumstances	–0.66
	Existence of significant tacit agreements and hidden rules	–0.65

Questionnaire items	Factor loading

Note: Underlined items indicate a significant regression with the labor accident rate or facility failure rate.

In order to improve the TSI value in an organization, it would be necessary to make efforts to raise the score of the questionnaire items if the score was evaluated as significantly lower than the total average score. Hence, through this analytical approach one can obtain specific clues for setting the direction of practical improvements.

Relation between safety performance and the questionnaire items

The performance indicators—the rate of labor accidents (RLA) and rate of facility failures (RFF)—were calculated for each plant. Data on accidents are based on reports provided to the public sector, which are drawn up according to regulatory laws. Here, multiple regression analysis was carried out in order to find the relation between RLA/RFF and all questionnaire items in Categories I, II, and III. The level of significance was set at 1% and 5%. Tables 5.5 and 5.6 show the results of the regression analysis. The "positive factors" are the items that bring down the RLA/RFF. Several similar questionnaire items were found to have a significant regression in relation to both RLA and RFF.

The most important objective for plant safety managers is to reduce RLA or RFF. They should therefore make efforts to raise the positive factors and/or reduce the negative factors. Keeping the need for such efforts in mind should help safety managers to formulate and design pragmatic countermeasures.

Table 5.5 Questionnaire items having a significant regression (<5%) with the labor accident rate

	Safety awareness and behavior	Safety management	Organizational climate and culture
Positive factors		Taking actions for improvement initiated by workers' ideas and opinions	Supervisor being in a position to give effective advice and make proper checks
	Managers paying attention not only to workers' private issues but also to productivity and safety		
	Proper personnel changes being made and assigning the right person for each job		
	Making efforts to find dangers and unsafe spots		
	Challenge for innovations because not satisfied with the present status		
	Periodic revising of safety rules and guidelines		

	Safety awareness and behavior	Safety management	Organizational climate and culture
	Actively pursuing quality assurance	Organizational climate addressing workers' abilities and personalities	
	Administrative staff placing importance on safety education and training		
	Placing a greater emphasis on hardware and software countermeasures		
	Feeling safety education and training are practical and helpful		
Negative factors	Preferring to work in a safe workplace		Preferring to obey unconditionally what
Not connecting potential accidents to one's own work ways		management instructs Avoiding responsibilities if a problem occurs	
Regarding safety as an organizational concern, not an individual one		Different supervisors making different demands on the same person	
		Being influenced by insufficient planning	

Table 5.6 Questionnaire items having a significant regression (<5%) with the facility failure rate

Safety awareness and behavior	Safety management	Organizational climate and culture
Giving colleague a caution if he does not follow rules and procedures	Distributing information about lessons learned and accident information to workers in an effective way	Effectively passing down technology skills and know-how to younger workers
Taking pride in job	Building a forward-looking work environment by taking up people's ideas and opinions	
Taking pride in company	Headquarters and upper management paying attention to job safety	
Making an effort to do work pleasantly, working together with all one's colleagues		
Addressing implications of past accident experiences in present safety activities	Distributing information about lessons learned and accident information to other workers in an effective way	

Safety awareness and behavior	**Safety management**	**Organizational climate and culture**
Feeling satisfaction in doing one’s work		
Feeling one’s contributions are important to the workplace	Management participating in safety education and training	
Supervisor having enough capacities and availability to be relied on		
Always reporting crucial information to supervisor		
Systems in place for reporting problems in safety to management board		
Participating in safety education and training	Supervisor being able to give effective advice and make checks	
	Managing and quickly responding to unsafe situations and deficiencies	
	Management placing trust in workers’ abilities and capacities	
	Administrative staff placing importance on safety education and training	
	Atmosphere of cooperatively working with one another	
	Feeling safety education and training are practical and helpful	Supervisor giving clear suggestions and correctly timed instructions on plan and progress of work
		Providing specific declarations of goals and policies in workplace
		Clearly defining the role-sharing involved in tasks

DISCUSSION

CRIEPI expects that CSAS will offer the following functions and features:

1. CSAS will address not only straightforward safety activities, but also comprehensive safety issues involving organizational climate, safety management, and workers’ safety awareness and behavior.
2. Safety will be a part of organizational concerns, and also of assessment items, including general organizational issues.
3. It will offer a comprehensive safety indicator, which shall be validated by other objective indicators.
4. CSAS will be able to assess labor safety and facility safety separately.
5. It will grasp the weak points in the safety features throughout the organization, using several indicators.
6. The evaluation results will lead directly to concrete safety improvements.

CSAS will be a unique safety assessment tool covering a range of safety concerns and issues, from workers’ safety awareness to organizational factors. Past systems, such as the workplace safety assessment tool developed by the Railway Technical Institute, have mainly been concerned with safety awareness and workplace problems among fieldworkers (Akatsuka & Ikeda, 1989). The various safety attitude indexes also emphasize workers' behavior. Following the Chernobyl accident, the ASCOT (Assessment of Safety Culture in Organizations Team) guidelines (Aro et al., 1996) developed by the IAEA and the Safety Culture Promotion guidelines (Booth, 1996) developed by the British Health and Safety Executive focused on enabling managerial boards to recognize problems themselves. Thus, these tools mainly deal with the relationship to regulators, the design of a safety system, and company policy. There was, however, little concern with individual behavior and awareness.

CSAS deals with items from individual awareness to organizational factors covering a wide range of relevant aspects (see Figure 5.1). Furthermore, the questionnaires also include general organizational factors that do not seem to be directly related to safety, as proposed by Litwin and Stringer (1968) and Likert (1959). It is necessary to verify the sensitivity of chosen items for use as an assessment tool. As shown earlier (see the section "Test of significant difference between plants"), over 90% of items have shown a significant difference between plants; these items were then used to identify the plant safety level (Figure 5.2). This result suggests that CSAS could effectively identify differences between plants. Moreover, differences between industries could be detected for over half of the questionnaire items. Therefore, the norms (industry average) must be prepared for each industry when an assessment is requested, because backgrounds, experience, detailed job contents, and instructions will differ.

As mentioned above, these questionnaire formats could identify differences between plants and between industries with enough sensitivity and could also satisfy functions (1) and (2) listed at the beginning of this section. Furthermore, it was suggested that the questionnaire collection and selection process would be satisfactory. With respect to function (3), the TSI could be obtained through principal component analysis. The TSI can be used as an index of comprehensive safety when assessing an organization.

Moving on to function (4), the relation between the indexes of safety performance and the TSI was ascertained because the RLA and the RFF could be determined separately for each plant. As Figure 5.3 shows, significant regression (1%) was identified between the TSI and RLA/RFF. This result implies that the accident rate could be reduced if the TSI were increased through ongoing efforts. Our findings also suggest that the TSI can be effective to labor safety and facility safety. In addition, Tables 5.5 and 5.6 suggest that this questionnaire survey can be independently applied to both labor accidents and facility failures. Of course, there is a common domain for both safety issues.

With respect to function (5), because there are 122 questionnaire items, it would be difficult to grasp all of the features related to safety issues in a short time. Moreover, with respect to the safety assessment, it would be convenient to discover the weak points or tendencies of organizational features by reviewing several indicators. Hence, 122 items were classified into 20 groups (Table 5.3). A standardization was completed for each group, calculating a total average among all plants. The standardized value can also be calculated for each group. The standardized value for each plant is obtained through the following procedure: S=Avi/Avt (Avi: group average of each plant; Avt: total group average of all plants). After this calculation, the standardizations for 20 groups are depicted in a chart; this chart then forms a safety profile for each plant. An example of safety profiles is shown in Figure 5.4. The plants A, B, and C correspond to those shown in Figure 5.2. This profile depicts plant features and weak points in a way that can be grasped easily.
The values were standardized by the total group average among plants, corresponding to 1.0.

As Figure 5.2, Figure 5.4, and Tables 5.4–5.6 show, safety managers can obtain several clues and useful information to help them make pragmatic actions for improvement. The effectiveness of the analyses has been verified by the significant correlation with both labor accident and facility failure rates. In addition, the important safety issues shown in Tables 5.4–5.6 were duplicated with issues obtained through interviews

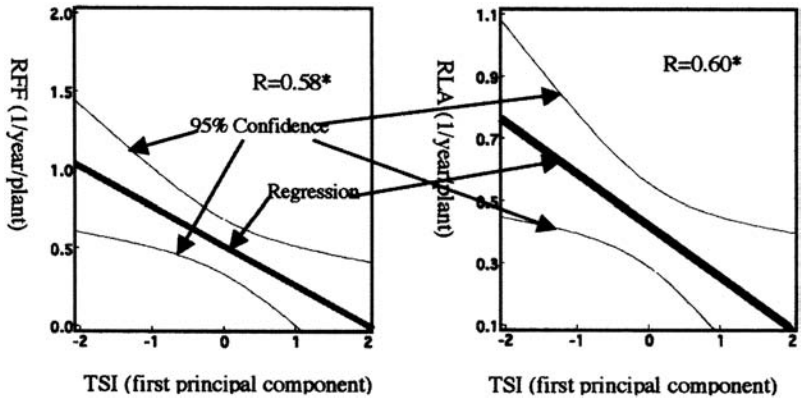

Figure 5.3 Results of regression analysis between the total safety indicator (TSI) and the rate of facility failures (RFF; left-hand side) and the rate of labor accidents (RLA; right-hand side).

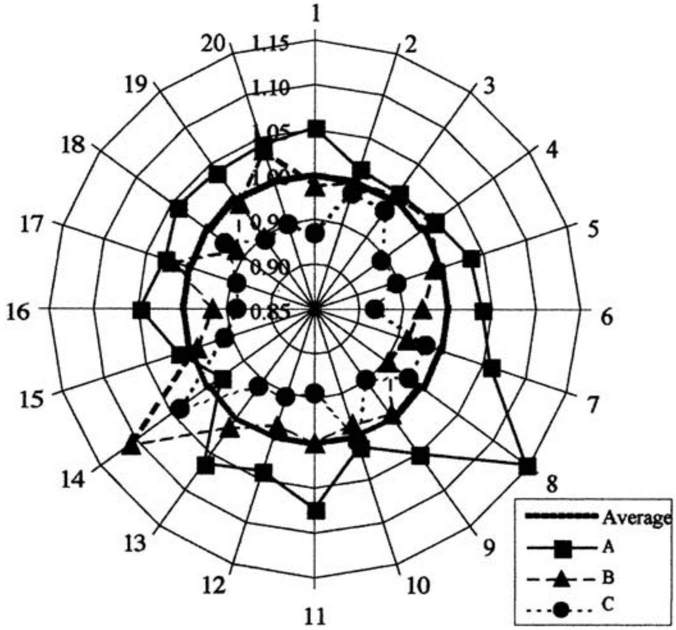

Figure 5.4 Example of the safety profile for plants A, B, and C (corresponding to A, B, and C in Figure 5.2).

and intensive field observation of work processes. Based on the clues and information obtained, concrete actions should be taken. Thus, researchers have been collecting examples of specific action plans from "safe companies"; these examples were summarized and published in the booklet shown in Figure 5.5 (CRIEPI, 2002). This booklet contains information on how to connect the safety profile to specific safety actions, thereby satisfying function (6).

CSAS will be an effective assessment tool to help overcome the weak points of an organization by making both safety and the effects of safety efforts "visible." In doing so, it will contribute greatly to the self-monitoring of organizations.

Figure 5.5 Summary of safety actions and policy implementations in "safe companies," proposing concrete safety plans based on the safety profile shown in Figure 5.4.

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CHAPTER 6
TOWARD A SAFETY CULTURE EVALUATION TOOL

Maomi Makino, Takeharu Sakaue, and Shiichiro Inoue

According to the Safety Preservation Rules required by the Japanese nuclear energy regulatory agency, safety preservation activities at nuclear power plants must be built upon safety culture. To evaluate activities based on safety culture, the cultivation of safety culture within a nuclear power plant must be measured and evaluated. To meet this challenge, further improvements to the Safety Culture Evaluation Support Tool (SCEST) have been made. The tool was applied to seven industrial organizations to test its appropriateness and practicality. Statistical standardization procedures were performed on these data. The target data of this standardization were the group evaluation score (managers, supervisors, workers) and the intergroup gap score (between three hierarchical levels). When SCEST identified weak points in an organization, interviews were conducted with the relevant managers, supervisors, and workers who participated in the evaluation. Through this step it was confirmed that SCEST could be a useful tool for evaluating safety culture in organizations.

INTRODUCTION

Japanese nuclear safety regulations have focused on ensuring safety from the perspective of hardware, and since the early stages of nuclear power development in Japan, these regulations have aimed at overcoming hardware-related troubles in nuclear installations. The regulations have been established, and any such troubles have been handled. However, the regulations have not covered instances like the criticality accident at JCO Company Ltd., nor have they covered intentional deception, such as the data falsification incident at a mixed oxide fuel demonstration facility in Great Britain. It has been pointed out that the existing regulatory process is not sufficient to prevent such instances. Such instances are brought about more by problems in connection with the soundness of safety management, such as the cultivation of safety culture and quality-assurance activities. Therefore, the challenge for the top management of each organization and regulatory body is how to cope with the issue of such safety management (Advisory Committee for Natural Resources and Energy, 2001).

Through the amendment of the Reactor Regulation Law in 1999, following review of the JCO criticality accident, the Nuclear Safety Inspection System was established and the Safety Preservation Rules were refined in an attempt to further improve nuclear safety maintenance. This inspection system is the so-called regulatory system from a human or organizational perspective; the nuclear safety inspectors, who are stationed at each nuclear installation, confirm compliance with the Safety Preservation Rules. According to the basic policy of the Safety Preservation Rules, the safety preservation activities in nuclear power stations must be built on safety culture. Moreover, the Nuclear and Industrial Safety Subcommittee Report of June

2001, entitled *Infrastructures of Nuclear Safety,* proposed an initiative to improve the framework of the nuclear safety regulatory system by reinforcing inspections and audits from the software aspects, such as efforts to cultivate safety culture and efforts by business operators to promote quality-assurance activities (Advisory Committee for Natural Resources and Energy, 2001).

In order to respond to these requests, the following are needed to cultivate a safety culture. First, an evaluation of the present safety conditions of an organization is required. The evaluation viewpoint establishes the concrete evaluation techniques of the safety culture aimed for. The second step is to build effective countermeasures for overcoming problems, once the weak points of an organization are identified through this technique.

In order to further the above two aims, we are now developing the "Guide Manual for an Understanding of Safety Culture and Evaluation." These guidelines are to include a methodology for determining the present condition of an organization—this will be a concrete tool—as well as specific strategies for the improvement of the organization (e.g., improvement of its educational programs). Moreover, the provision of suitable countermeasures, among other things, will be presented to support the inspectors when the weak points of an organization are identified through their inspection of whether or not the safety preservation activities are being carried out within a well-cultivated safety culture.

This chapter introduces the results of a study on the Safety Culture Evaluation Support Tool (SCEST), which comprises the core of a series of research projects on human and organizational factors (Institute of Human Factors, 2001, 2002).

STRUCTURE OF SCEST AND METHOD OF INVESTIGATION

Basic items in SCEST

The SCEST concept is based on the ASCOT guidelines. The 38 basic items included in this tool are shown in Table 6.1.

Table 6.1 Basic items in the Safety Culture Evaluation Support Tool (SCEST)

Evaluation category			Subcategory	Basic items
01.	Safety policy statement	01.	Recognition of policy statements	Has the company issued safety policy statements?
		02.	Understanding of policy statements	Can you give the policy statements from memory?
		03.	Revision of policy statement	Are the policy statements occasionally revised?
		04.	Penetration of policy statement	Can you recall the policy statements when a problem occurs?
02.	Safety and productivity	05.	Understanding safety conditions	Are the safety targets, costs, performance, irregularities, and so forth explained?
		06.	Priority of safety	Has there been any change in the work schedule due to safety issues?

Evaluation category			Subcategory	Basic items
		07.	Involvement in safety	Have you ever expressed an opinion about deadlines from the standpoint of safety?
		08.	Recognition of priority	Would you accept sacrificing productivity for the sake of safety?
03.	Safety regulations and documents	09.	Documentation	Are security measures and decisions put into writing?
	10.	Improvement of manuals	Are errors in manuals promptly corrected?	
		11.	Observance of manuals	Are deviations from manuals reported?
04.	Responsibilities, authorities, and roles	12.	Understanding the site	Are you aware of the actual conditions at the site?
	13.	Authority for safety	Is your authority on safety sufficient?	
		14.	Revision of roles	Are staff members immediately informed of any change in their roles for the benefit of safety?
		15.	Participation in improvement	Have you been involved in locating irregularities and in implementing improvements?
05.	Troubleshooting	16.	Experience in accident analysis	Have you ever made an analysis of an accident?
		17.	Analysis of human factors	Do you make analyses of human factors in irregularities?
		18.	Reporting procedures	Do you have a procedure for reporting individual errors and a means for keeping them secret?
		19.	Planning and strengthening of countermeasures	Do you immediately take actions to tackle individual errors or unexpected phenomena?
06.	Education and training	20.	Provision of training	Are you trained in safety or in education?
	21.	Assessment of training	Are the plans and the results of training sessions appropriately assessed?	
		22.	Improvements in training	Are there any suggestions for training people on-site?

Evaluation category			**Subcategory**	**Basic items**
		23.	Training for troubleshooting	Are there any training sessions to fix irregularities that involve human factors?
		24.	Putting lessons to work	Do you always give shape to the lessons learned from troubles?
07.	Information channels and communication	25.	Top-down channel	Are copies of notes from safety meetings distributed to staff on-site?
	26.	Communication	Can you discuss aspects of business operations with people on-site?	
		27.	Bottom-up channel	Do the executives have talks about safety with people on-site?
08.	Work environment	28.	Controlling environmental conditions	Are the space and conditions adequate for safe work?
		29.	Attitude toward improvement	Are there any measures to take when the work environment is not improved?
		30.	Recognition of improvement	Are there many cases in which a problem found in the work environment has been alleviated?
09.	Safety actions	31.	Use of safety system	Has a system for reporting defects been put in place, or have improvements been made?
		32.	Assessment of safety actions	Are those staff members who have pointed out problems shown public appreciation?
		33.	Safety indexes	Are there easy-to-understand indexes to show safety performances?
		34.	Organization-wide actions	Does administrative staff conduct safety actions?
		35.	Use of research institutions	Have you asked any third party to examine your safety measures?
10.	Safety management	36.	Outsider's inspection	Do inspections by outsiders prove helpful to your operations?

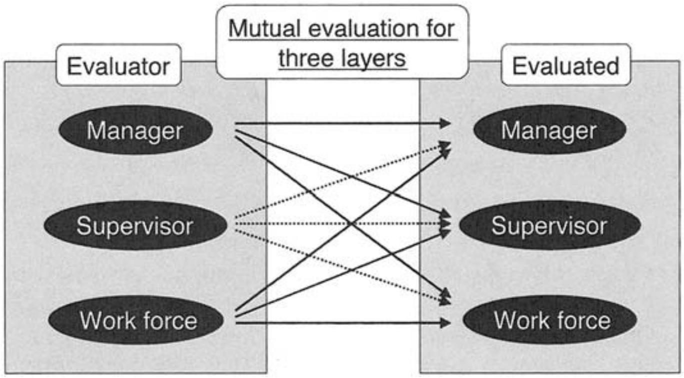

Figure 6.1 Evaluation system of SCEST.

Evaluation category		Subcategory	Basic items
	37.	Corporate partnership	Are there any safety provisions in the partnership contract?
	38.	Selection of managers	Do the criteria for selecting managers reflect safety matters?

Evaluation system of SCEST

The items in the ASCOT guidelines include various evaluation subjects, such as organizational procedures, one's own behavior, and others' behavior. The items in SCEST evaluate the behavioral aspects of three hierarchical levels: managers, supervisors, and workers, including oneself (see Figure 6.1).

The number of items to which each respondent replied was 114 (38 items multiplied by 3 hierarchical levels) and included questions such as "Do your managers know that safety statements are issued in this organization?" All responses were made on an eight-point scale ranging from (1) "Not at all" to (8) "Extremely." We adopted this evaluation system in order to use two types of safety culture index: the value of each item and the value of the evaluation gap between each level.

Procedure

SCEST includes interview methods in the investigation procedure in order to subsequently monitor whether improvements in an organization, as identified during a SCEST check, actually were made. The procedure can be outlined as follows:

1. An explanation of the system for checking questionnaires is given to the safety manager and the safety control person in the organization concerned.
2. SCEST distribution: the staff of the organization and our team discuss together how best to present the questionnaires, how to distribute them to participants, and how to collect them.
3. Data collection: usually data are collected via mail (in order to exclude the intervention of managers).

4. Collected data arrangement: intelligible display methods, such as profiles and diagrams, are applied.
5. Feedback: explanations are provided to the safety manager and the safety control person in the organization concerned.
6. Interviews among three hierarchical levels of members are conducted (based on SCEST results).
7. A proposal for improvements is presented to the safety manager and the safety control person in the organization concerned.

Subjects and statistical processing

SCEST was implemented in seven organizations, which included industrial organizations involved in nuclear power production as well as organizations in the manufacturing industry and the construction industry. The data were collected from a total of 1, 087 persons, including 125 managers (mean age: 48.5 years; mean working time: 20.0 years), 158 supervisors (mean age: 43.9 years; mean working time: 17.9 years), and 804 workers (mean age: 33.7 years; mean working time: 11.0 years).

Next, in order to enable comparisons among these organizations, statistical normalization was performed (mean: 4.5; standard deviation: 1) on the values acquired from each level (i.e., managers, supervisors, and workers). A cross-comparison among the above-mentioned organizations was carried out on the basis of these normalized data. The results for Organization B and Organization C are as follows.

RESULTS

Results for Organization B (industrial organization in nuclear power production)

Because Organization B was recently founded, the establishment of its organizational and functional assignments is still at an early stage. Therefore, neither side of management has had time to improve. The respondents in Organization B were 30 managers (an average of 49.3 years old; mean seniority: 6.3 years), 46 supervisors (an average of 42.4 years old; mean seniority: 2.6 years), and 191 workers (an average of 28. 0 years old; mean seniority: 7.6 years). They responded to various statements (114 in total) using an eight-point Likert scale.

Results for each hierarchical level

The evaluation results for the managerial level are shown in Figure 6.2. As shown in this figure, many items fall far short of the standardization average value of 4.5. On the other hand, the evaluation gaps between the hierarchical levels are small. That is, every level is low relative to the managerial level. The supervisor level is a little higher than the manager level in evaluation criteria such as “recognition of priority” and “documentation.” However, as a whole, the level falls far below the average in many evaluation criteria. Moreover, this tendency also can be seen between hierarchical levels, and there is almost no gap between the levels. The evaluation result for the worker level is also below average in many items, and here, too, there is no gap between hierarchical levels.

Interviews

Having put the above results together for Organization B, we found that the evaluation value is low to moderate in the three hierarchical levels and that these values are in agreement among the levels. These results

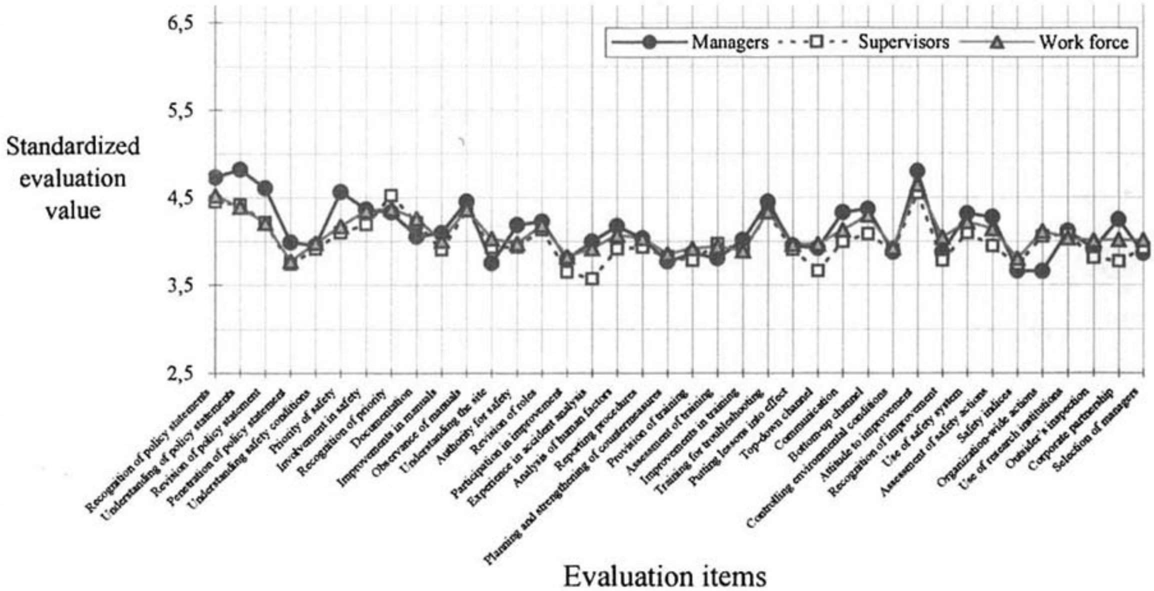

Figure 6.2 Result of evaluation for managerial level in Organization B.

indicate that each level (managers, supervisors, workers) recognizes where many safety problems are latent in their organization. That is, although evaluation values are low, this can be interpreted as the vector of evaluation having gathered in each of the levels.

The questionnaire results are relatively low in items such as "participation in improvement," "planning and strengthening of countermeasures," and "provision of training." Therefore, exploratory interviews relevant to these items were conducted. In response to the item on "participation in improvement," several managers stated, "Even if those participating think that something should improve, I do not say that it should improve because it is not within my work responsibilities." This statement implies an increase in the unwillingness to make improvements in the entire organization. The same attitude is evident in the following remark by a supervisor: "The man who is able to spontaneously tackle a problem rarely makes it into this organization, and almost all men must be directed by someone to do something, or they do not act."

Moreover, many managers and supervisors described the "planning and strengthening of countermeasures" as follows: "Indeed, there has been discussion, but nobody will take concrete action," or "The speaker is made to take the responsibility for pending, open questions." Most likely, such utterances express the passive attitude of the entire organization.

Also in relation to "provision of training," a manager said, "There is no systematic training system," and a supervisor stated, "There is no tradition that teaches technology from top to bottom." The workers insisted, "Because there are no instructions covering working methods, there are no methods except actually doing and memorizing." Thus, a situation in which education and training are of low quality has been identified for this organization.

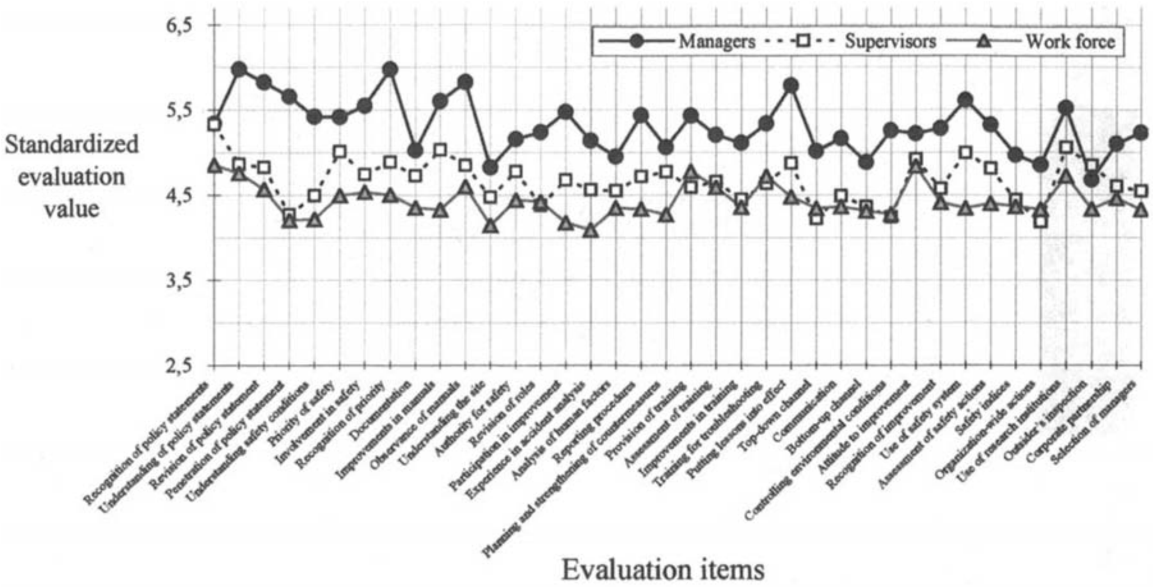

Figure 6.3 Result of evaluation for managerial level in Organization C.

As mentioned above, it is thought that an item with a low evaluation value in this questionnaire is in agreement with a problem of this organization as grasped by employees in their everyday work. That is, this result seems to indicate that the tool has some validity. Organization B is just now beginning to build various organizational systems. Hence, each level is in agreement, and it is assumed that the weak points already have been clearly recognized. This result will prove that an index's gap value can also fully express the actual conditions in an organization.

Results of Organization C (industrial organization in nuclear power production)

The respondents in Organization C were 2 managers (an average of 54.5 years old; mean seniority: 35.5 years), 21 supervisors (an average of 41.7 years old; mean seniority: 23.4 years), and 84 workers (an average of 27. 6 years old; mean seniority: 8.9 years). However, in this organization the data on managers is quite limited. The evaluation of the managerial level of the entire organization is difficult.

Results for each hierarchical level

The evaluation results for managers are shown in Figure 6.3. One characteristic point is that a manager's self-evaluation is very high. However, managers as a group received a low evaluation from supervisors and workers. The workers in particular evaluated the managerial level at less than the standard average value of 4.5 for many items. Therefore, the gap between managers and the work force is quite considerable.

The evaluation of supervisors by managers is high compared with the mean for supervisors. Moreover, relatively high evaluations also were given by the supervisors themselves and by the workers in their evaluation of the supervisors. Hence, the evaluation gap is small. However, for some items the same large gap found between managers and supervisors is also found between managers and workers.

The managers gave comparatively high evaluations to the workers as well. However, for items such as "documentation," "participation in improvement," and "use of research institutions," the evaluation of workers is low. On the other hand, the supervisors gave workers a somewhat higher evaluation than the workers did themselves. As a result, the evaluation gap varies considerably depending on the item.

Interviews

Organization C has a long, established history. Hence, various activities related to safety have already been carried out, and the evaluation value of SCEST is high. However, there is quite significant variation between evaluation items. Moreover, the gap value between managers and others is large. The interviews focused on the size of this variation and the gap value.

According to the results from the interviews, there was a great deal of dissatisfaction from supervisors toward managers. Comments such as the following were made: "An organization becomes huge, and there is no support system that can respond immediately to an emergency," "there are few opportunities for a manager to come to the site," "their grasp of on-site issues is insufficient," and "because cost-cutting and management measures are decided top-down, these decisions rarely reflect the opinion of on-site staff." These results express the insufficiency of managers' understanding of on-site issues and the lack of communication between management and on-site supervisors and workers. We suspect that the former is indicated by the size of the variation in evaluation values, and the latter is indicated by the size of the gap values.

Organization C is evaluated as an organization with a high level of safety culture in terms of evaluation values. However, in terms of gap values it is evaluated as an organization with a low level of safety culture. This results from reassessing and appreciating its significance (the need to verify validity) and from conducting interviews around the same time as the distribution of the questionnaires.

Managerial practices in Organization F (construction industry)

We examined some managerial practices of Organization F, which had the highest value according to SCEST among seven organizations. Organization F is involved in major construction work. This organization, which had been recognized by the Labor Standards Inspection Offices as a superior safety control company, had had no accidents for three months since the beginning of the construction work that was being performed at the time of our investigation.

Safety performance indexes

It was revealed that there are very frequent on-site safety patrols by managers (at least three times a day). The managers look for indications of risk factors and caution workers daily on the spot. Furthermore, they attempt to carry out informal talks with workers when the opportunity arises.

In a three-month period there were only three items described in the patrol report, and these matters were not relevant to human behavior. That is, there were no incidents concerning rules and morals (such as disorderly dress), which frequently appear on the patrol reports of many construction sites. Moreover, the results of our interviews show that these items were pointed out in daily meetings. This organization not only performs safety activities independently, but also systematizes these activities, thereby attaining superior organizational performance. The contents of a previous meeting could be easily checked on personal computers, documents, on-site bulletin boards, and the like.

As for safety indexes, a table showing the point of a safety control was specified. In addition, a table covering items indicated by the managers and the supervisors was periodically created as well. In addition, a table showing how many of those items had been improved was distributed at the site. Various problems were displayed on these tables, and the concrete instructions (24 in total) were carried out. Moreover, the construction work area was always clean and organized. This exceptional safety performance (i.e., a record of no accidents) is probably continuing as a result of such positive management.

Correspondence with the SCEST results

In Organization F, 20 managerial practices corresponded with the high-score items in SCEST. On the other hand, it is interesting to note that managerial practices concerning the low-score items in SCEST were insufficient. Such a result might be expected because the period for obtaining performance data was short. However, with regard to the sensitivity of SCEST, the values of the items relevant to inadequate practices, when low, might prove that this evaluation tool is accurately reflecting the state of the organization.

CONCLUSION

SCEST classifies an organization into three hierarchical levels and asks respondents for a self-evaluation and an evaluation of the other two levels. Its evaluation of an organization is based on two aspects: the item value and the gap value between each level. The introduction of the latter index is based on the view that safety culture cannot be cultivated if an inaccurate image exists among the three hierarchical levels of an organization. After all, two important aspects of safety culture are that the safety consciousness of organizational members does not differ significantly from one individual to the next and that the information channel runs smoothly in the organization. Using the questionnaire and interview techniques, this study confirmed that SCEST can easily evaluate the safety culture in an organization from two perspectives.

In order to improve SCEST the following points must be pursued. The first problem is that relatively little data are available from managers and supervisors. In order to confirm the validity of SCEST sufficiently, we need to accumulate further data for both these levels. Second, it is necessary to use longitudinal methods to measure how each evaluation value changes. Consequently, because it will become possible to examine the relationship between actual managerial practices and the values, the sensitivity of SCEST shall become clearer. Finally, we were unable to perform a general evaluation of safety culture in this study. Therefore, it is necessary to develop a general-evaluation index as well, which will enable comparison between organizations.

The reliability and validity of SCEST will improve if these additional steps are carried out. Once these improvements are made, we expect that SCEST not only will assist the members of an organization to recognize clearly the vulnerable points latent in the organization, but also will function as a driving force to enhance safety culture.

Acknowledgment

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CHAPTER 7
SAFETY CLIMATE AT NUCLEAR POWER PLANTS IN TAIWAN

Shang Hwa Hsu and Feng-Liang Lee

In this chapter we identify the characteristics of safety climate at nuclear power plants in Taiwan, explore the factors that are sufficient to discriminate between high and low safety-awareness and safety-compliance groups, and provide a theoretical framework to explain the interrelationships among factors underlying safety climate. Safety climate scales for managers and workers were developed on the basis of local safety climate issues identified through focus-group interviews. Survey results reveal that although both managers and workers had a positive attitude toward safety climate, they differed on several dimensions. Discriminant analysis found that a combination of organizational factors and a safety management system could account for differences between high and low safety-awareness groups. In addition, the existence of a safety management system and provision of safety equipment can serve as indicators of the measure of safe compliance.

INTRODUCTION

Safety culture has been recognized as a major contributor to the safety of high-risk systems. This notion is supported by several studies revealing the direct or indirect relationship between safety culture and safety performance. For example, Guest et al. (1994) found that groups with a higher accident rate had negative attitudes toward safety responsibility and tended to attribute accidents to other people.

In the nuclear power industry, the concept of safety culture was introduced by the International Atomic Energy Agency (IAEA) following an investigation of the Chernobyl accident (International Nuclear Safety Advisory Group [INSAG], 1986). In a later report (INSAG, 1991), the IAEA further elaborated the definition of safety culture in detail and provided a set of safety culture indicators. Following the IAEA suggestion, power companies and government regulatory agencies have established evaluation programs to assess their safety culture on a regular basis and have initiated efforts to improve safety culture.

Although practitioners have developed several scales to assess safety culture (e.g., Cox & Cheyne, 2000; Ostrom et al., 1993), many researchers (e.g., Mearns & Flin, 1999; Zohar, 1980) have questioned the validity of these scales from a theoretical standpoint and have also questioned their ability to measure safety culture. Referring to the concepts of organizational culture versus organizational climate, they have argued that there is also a distinction between the concepts of safety culture and safety climate. Safety culture is the values, beliefs, attitudes, norms, and underlying assumptions that employees hold about the safety of an organization. It is a complex, enduring trait that is difficult to measure. Safety climate describes employees' perception about and attitudes toward the current work environment (Zohar, 1980), but it also provides a snapshot of the state of safety culture. Researchers recommend safety climate as the preferred concept, for it can be readily measured through the use of survey techniques.

Yet which factors of a safety climate scale should be included in safety climate questionnaires? There has been no consensus on the specific dimensions to be included in the measurement of safety climate (Booth, 1996; Cooper, 1998; DeJoy, 1994; Guldenmund, 2000; Ostrom et al., 1993; Williamson et al, 1997). Furthermore, Glendon and Litherland (2001) found that there was no identical set of safety climate factors that can be applied to all organizations. The difficulty in defining specific dimensions for safety climate measurement may lie in the problem that safety culture is part of organizational culture, which is also influenced by national culture. The empirically derived factors may be specific to the organization studied. Thus, it is necessary to examine the structure of factors related to safety climate in the specific organization before benchmarking with other organizations can begin.

The promotion of safety has become one of the central objectives of organizations (Booth, 1996; Cooper, 1998, 2000; Lee & Harrison, 2000). In the past, the cause of an accident was attributed to employees' unsafe behavior. As a result, measures to improve safety focused on the individual level; that is, on changing employees' attitudes toward safety and on enhancing employees' job competencies. However, recent accidents have shown that deficiencies in the interactions between social and technical systems were the root cause of the accidents (Leveson, 1995; Brown et al., 2000). Therefore, to effectively improve the safety of an organization one has to take a systems approach to reengineering the interactions of system components. That is, the safety improvement program should focus not only on remedying failures of each component within the system, but also on initiating system-level efforts that yield an optimal relationship between system components and that ultimately cultivate a good safety culture within the organization.

The present study addresses two questions on the improvement of safety culture. The first deals with how to improve employees' safety awareness and behavior. To develop a safety-awareness and compliance-enhancement program, it is necessary to know which safety climate factors determine the level of employees' safety awareness and compliance. If these factors are not considered in the improvement program, the effectiveness of this program will be diminished. The second question concerns how one might reengineer the socio-technical system so that safety culture can be optimized. Developing a program cultivating a good safety culture requires an understanding of how safety climate factors interrelate and what the dynamic process in a positive safety climate is. It is therefore necessary to develop a safety climate model that describes the intertwined relationships of safety climate factors.

In sum, the purpose of this study was threefold: (a) to identify safety climate factors at nuclear power plants in Taiwan, (b) to investigate the safety climate factors that can discriminate between high and low safety-awareness and safety-compliance groups, and (c) to develop a model showing possible causal relationships among safety climate factors.

METHODS

Development of the safety climate scale

The development of the safety climate scale consisted of three stages: (a) to identify issues pertaining to safety climate, (b) to develop an item pool for the safety climate scale, and (c) to examine the reliability and validity of the scale.

Identification of safety climate issues

A literature review was conducted to examine dimensions of safety climate (Cooper, 2000; Cox & Cheyne, 2000; Fli et al., 2000; Glendon & Litherland, 2001; INSAG, 1991; Zohar, 1980). The themes included in the studies fell into two categories: organizational factors (e.g., management commitment, work environment, organizational policies, training, procedures, safety practices) and individual factors (e.g., risk perception, safety awareness, safety compliance).

Structured interviews with managers and workers were conducted to elicit employees' attitudes toward the company's management and safety policies, as well as their opinions about training, procedures, the human-machine interface, and provision of safety equipment. Seventeen focus groups were held. The interview protocols were analyzed by using the techniques of open coding, axial coding, and selective coding proposed by Strauss and Corbin (1990). In addition, field observations verified the issues identified through interviews. The safety issues are summarized in Table 7.1.

Table 7.1 Safety issues for managers and line-workers

Issues	Managers	Workers
Safety awareness	1. Designing safety awareness practices	1. Assessing risks
	2. Sharing situation awareness	
	2. Promoting safety awareness practices	3. Detecting potential hazardous problems
	4. Briefing and simulating emergency conditions	
	3. Supervising and monitoring the implementation of safety practices	
	5. Carrying out self-checks and cross-checks	
		6. Reacting to emergencies
		7. Taking no shortcuts
Safety priority	1. Communicating the safety priority policy	1. Following the safety priority policy
	2. Placing emphasis on safety first	
	2. Placing emphasis on safety issues	
	3. Showing management commitment to safety	
	4. Allocating resources according to safety priorities	
Job design and personnel selection (teamwork and task assignment)	1. Definition of safety responsibilities and accountability 2. Promotion based on safety performance 3. Task assignment according to workload and task difficulty 4. Job rotation 5. Safety management for contractors	1. Performance amidst a workforce shortage 2. Task assignment according to personnel's capabilities and current conditions 3. Workload and time management

Issues	**Managers**	**Workers**
Communication and dissemination of safety policies	1. Downward communication and dissemination 2. Attention paid to communication techniques 3. Interdepartmental communication and coordination	1. System status reporting 2. Near-miss reporting 3. Communication among team members
Safety performance evaluation and root cause analysis	1. Safety performance assessment methods 2. Mechanism of feedback and sharing of experiences	1. Accuracy, breadth, and depth of root cause analysis 2. Sharing of experiences
Leadership and supervision	1. Participative management 2. Workers' initiative 3. Reaction to management and supervisor's participation	
Training	1. Identification of training needs and training program requirements 2. Content and tools for training 3. Implementation of training program 4. Assessment of training effectiveness 5. Improvement of training program	
Reward and punishment	1. Promotion and implementation of reward and punishment policy	1. Fairness 2. Effectiveness of reward and punishment policy
Compliance with procedures and safety practices	1. Timing of toolbox meeting 2. Content of toolbox meeting 3. Accident prevention and emergency procedures 4. Implementation of toolbox meeting 5. Scope of procedures 6. Design of procedures	1. Use of procedures 2. Compliance with procedures 3. Formulation of the details of procedures 4. Revision of procedures
Safety of facilities and protective equipment	1. Power plant facility planning 2. Plant management 3. Enhancement of human-machine interface and provision of personal protective equipment	1. Use of safety protection equipment 2. Verification of deficiencies in human-machine interface and personal protective equipment

Development of item pool

The issues identified served as the basis for writing the scale items. Because workers and managers had different concerns about safety issues, separate scales were developed for the managers and the workers. To ensure the scales' face validity, experts in nuclear power plants reviewed each question in the two questionnaires for clarity of the statements and for accuracy in reflecting the field situation. In addition, positively phrased and negatively phrased statements were balanced in order to avoid response biases.

Validation of survey questionnaire

The two revised questionnaires were administered to 53 workers and 34 managers. Cronbach's alpha reliability coefficient for the manager questionnaire was 0.83 and that for the line-worker questionnaire was 0.87. Factor analysis was conducted to assess validity. Principal components analysis of each domain, followed by varimax rotation of the emergent factors, was carried out. In each case the factors with high eigenvalues (minimum 1.0) were extracted. The full set of factors and the total variance that can be accounted for by these factors are shown in Table 7.2.

Table 7.2 Total variance accounted for by factors (managers and line-workers)

	Total variance accounted for	
Factors	**Managers (%)**	**Workers (%)**
Safety awareness	72.94	68.24
Safety priority	76.50	72.75
Job design and personnel selection (teamwork and task assignment)	77.64	68.75
Communication and dissemination of safety policies	72.42	70.21
Safety performance evaluation	75.33	71.75
Leadership and supervision	67.35	72.40
Training	77.10	75.50
Reward and punishment systems	69.96	71.15
Compliance with procedures and safety practices	76.20	75.71
Safety of facilities and protective equipment	71.75	65.06

After the validation process, the final scales were five-point Likert-type scales with 192 positively phrased and negatively phrased statements about safety attitudes for the manager level and 207 items for the line-worker level. There were 168 common items in the two scales. These items were used in the comparison of the management and line-worker subgroups.

Administration of the safety climate scale

The two scales were distributed to employees in the three nuclear power plants in Taiwan. A sampling method was used to specify the number of samples in order to achieve a 95% level of confidence in the data collection. The stratified sampling method was used to randomly assign 409 scales (i.e., 121 manager questionnaires and 288 line-worker questionnaires).

RESULTS

Survey results indicate that both managers and workers had positive safety attitudes (>3.0). Among the ten factors, the manager group scored relatively lower ratings for three factors: namely, "job design and personnel selection," "leadership and supervision," and "reward and punishment systems." In the worker group, the factors "teamwork and task assignment," "leadership and supervision," "reward and punishment systems," and "provision of safe facilities and protective equipment" obtained relatively lower rating scores.

Because the two questionnaires were similar, an examination of differences between manager and worker groups was made. T-tests were performed for each issue in the questionnaires. It was found that the manager group scored significantly higher ratings than the worker group did for the following factors: "safety priority," "job design and personnel selection (teamwork and task assignment)," "leadership and supervision," "training," "reward and punishment systems," "compliance with procedures and safety practices," and "provision of safe facilities and protective equipment."

Table 7.3 Means, standard deviations, and *p* values of t-tests for the manager and worker scores

	Managers		**Workers**		
Issues	Mean	St. Dev.	Mean	St. Dev.	***p* Value**
Safety awareness	4.0511	0.7222	4.0196	0.7023	.297
Safety priority	4.1102	0.7296	3.8968	0.8261	*<0.001*
Job design and personnel selection (teamwork and task assignment)	3.4865	1.0197	3.1018	0.9957	*<0.001*
Communication and dissemination of safety policies	3.9252	0.7131	3.8342	0.8549	.011
Handling of incidents and root cause analysis	4.0066	0.7705	4.0079	0.8152	.976
Leadership and supervision	3.5448	1.0081	3.3403	0.9626	*<0.001*
Training	3.8014	0.8802	3.6607	0.8970	*<0.001*
Reward and punishment systems	3.5959	0.9738	3.3131	1.0459	*<0.001*
Compliance with procedures and safety practices	4.0106	0.8745	3.9158	0.8361	*<0.001*
Safety of facilities and protective equipment	3.7580	0.8833	3.4462	0.9458	*<0.001*

An examination of the correlation matrix of "safety awareness," "safety priority," and "compliance with procedures and safety practices" indicated that safety priority was related to safety awareness and safety compliance. That is, workers responding positively to safety policy tended to have a higher level of safety awareness and stricter compliance. Discriminant analysis identified the safety climate factors that are sufficient to discriminate between high and low levels of safety awareness among workers. These factors were definition of responsibility, safety performance evaluation, leadership and supervision, training, reward and punishment, and provision of a safe facility and personal protective equipment (p<.05). The factors that enable discrimination between high and low levels of safety compliance among workers were safety awareness, safety priority, and communication (p<.05).

The interrelationships among these extracted safety climate factors were examined through the use of structural equation modeling techniques. As mentioned, we have proposed the use of a socio-technical model of safety climate. This safety climate model postulates that a system climate contains three levels of components: the socio-technical environment, the team, and the individual (Cheyne et al., 1998; Cooper, 1998, 2000).

In our proposed framework, the company's safety-first policy and management commitment direct the design and operation of organizational and technical subsystems (socio-technical factors). These socio-technical factors make up the context of an operational environment. The contextual factors determine the formation and operation of work groups. The work group factors and safety management system influence an individual's attitudes and predispositions (factors at the individual level). A person's individual factors then determine how safely he or she will behave (behavioral factors). The proposed model in this study (see Figure 7.1) was tested using covariance structure analysis procedures in the Amos program (Arbuckle, 1997). This model resulted in a satisfactory fit to the total sample data and was assessed by six fit indices (^{2}=273.

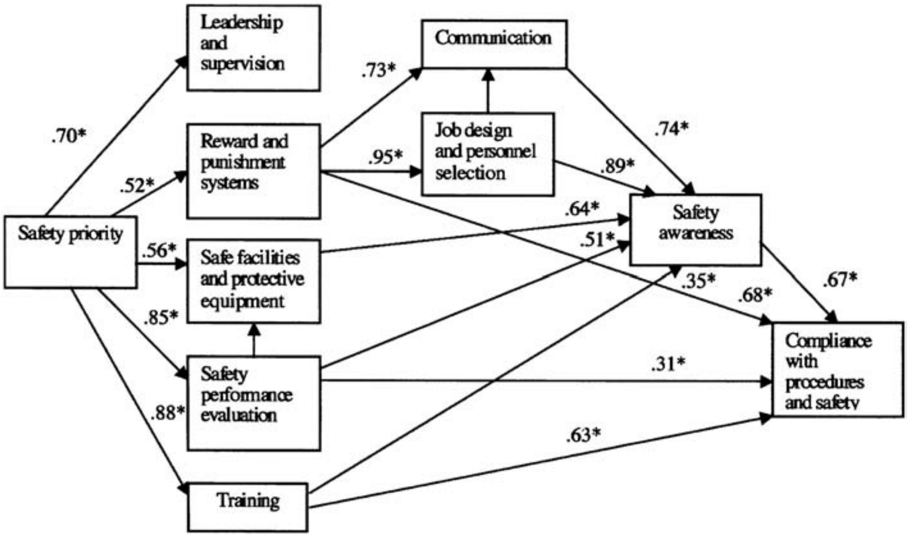

Figure 7.1 The proposed socio-technical model of safety climate. (*) indicates a statistically significant figure.

862, d.f.=166, ^{2}/d.f.=1.650, GFI=.832, CFI=.913, RMSEA=.074). Most of the model structural effects were statistically significant

DISCUSSION AND CONCLUSION

Survey results show that both managers and workers perceived positive safety climates. However, managers had higher ratings than workers did. The promotion of safety culture usually starts from top management and flows down to plant employees. Thus, the company still has some work to do in improving the level of safety practices among workers.

Taiwan Power Company initiated their safety culture campaign five years ago. Its effect has been reflected by a lower rate of incidents related to human error. The results of this study have pointed out several safety-related areas for improvement, thereby enabling continual improvement of the safety culture. These areas include leadership and supervision, job design and personnel selection (teamwork and task assignment), reward and punishment systems, and the safety of facilities and protective equipment.

Furthermore, the results of discriminant analysis reveal that workers with high or low safety-awareness levels differed in the following areas: definition of responsibility, safety performance evaluation, leadership and supervision, training, reward and punishment, and provision of safe facilities and personal protective equipment. Moreover, the factors that enable discrimination between workers with high or low safety-compliance levels were safety awareness, safety priority, and communication. This result brings implications for the design of short-term remedies for problems in safety awareness and behavior. For the technical subsystem, the human-machine interface of facilities and equipment must be improved. Safe facilities and safety performance evaluations can increase employees' risk perception and management. Training should be provided to enhance employees' competencies.

However, the allocation of resources for training and for improvements of the human-machine interface usually relies on management commitment and risk perception. Managers should therefore receive human factors training in order to gain a better understanding of the importance of compatibility between persons, tasks, and machines, so that they can make better decisions about the improvement of human-machine interfaces and task assignments. Managers also can use participatory management to improve their supervisory and leadership style. Moreover, managers should unambiguously define safety responsibilities, encourage organizational communication, and exercise fair reward and punishment policies in order to reinforce employees' safety awareness (O'Dea & Flin, 2001). At line-worker level, workers should understand safety-first policy, follow safe practices, maintain safety awareness, and openly communicate the perceived situation to their partners and supervisor.

In the end, the company should initiate efforts to reengineer its socio-technical system. Analysis through our descriptive socio-technical model provided suggestions for the priority and sequence of safety improvement programs and initiatives. Specifically, management commitment is the core component of safety culture. Employees must perceive this commitment. Safety-first policies serve as the basis for the design of the management subsystem (e.g., reward and punishment, training, and leadership and supervision) and the technical subsystem. Furthermore, the reward and punishment systems should provide effective reinforcement of safe practices and team operations (i.e., task assignments and communication). The team environment and the safety of the technical subsystem can influence employees' safety awareness, which in turn has an impact on safe behavior.

Finally, a safety management system should be established. The safety management system should be composed of three components: the safety quality and service system, the safety evaluation system, and the safety management information and knowledge system (Cooper, 1998; Griffin & Neal, 2000; Wahlström, 1999; Yamaguchi & Tanaka, 1999). The safety quality and service system sets the goals of the organization's safety performance and prescribes the methods to achieve safety goals. The safety evaluation system enables managers and safety professionals to define appropriate safety performance measures, evaluate safety performance on a regular basis, and identify root causes whenever incidents or accidents occur. The result of a safety evaluation should be communicated to employees through the safety management information and knowledge system. This feedback can increase the accuracy of risk perception as well as promote organizational learning.

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PART THREE

The Search for Adequate Response

INTRODUCTION

The five chapters of this volume's Part Three give examples of difficulties and successes of optimizing measures and attempts to introduce safety-oriented measures in nuclear plants. In Chapter 8 Schöbel offers a theoretical model of rule compliance. It postulates the interaction of three "environments" regulating the safety-oriented behavior: the information provided by the rule itself, the nature of the task at hand, and the social environment, that is, the possibilities of social interaction of the rule user with its social norms. It is assumed that the informed manipulation of these three environmental factors will enable rule compliance.

The following chapter by Fahlbruch reports on educational concepts, didactics, and conduct of training for nuclear management and supervisors (N=196). Based on theoretical elements of the open socio-technical systems approach, the objectives of the 24 training sessions covered critical safety cultural features: questioning attitude, systemic thinking, superiors as models, and professional identity. The chapter concludes with a proposal as to how a sustained safety culture may be influenced by training interventions in nuclear plants.

The JCO criticality incident in Tokaimura (1999) and the resultant lessons learned are the focus of Chapter 10 by Tanabe and Yamaguchi. The authors pursue a two-pronged analytic approach, both from the technical system as well as from the actors' perspective. In doing so they use theoretical propositions advanced by Rasmussen. The authors show that changes introduced over time in the production system, as well as erroneous mental models of the operators due to poor advance training, substantially contributed to the incident.

Becker, in Chapter 11, illustrates the influence of the Seveso II Directive of the Commission of the European Union to promote safety management systems in the nuclear industry. This tends to shift also the regulatory focus from rule-based to goal-based control. It also puts the responsibility for safe operations more squarely into the domain of utility management. However, cost reduction programs through personnel reduction measures in the German nuclear industry as reactions to increased competition may threaten positive impacts on safety management systems.

Chapter 12 by Cox, Jones, and Rycraft describes an intervention technique—the behavioral safety program which originally started out as a conventional program related to vocational safety aspects. The program has recently been extended also to two nuclear power plants. A combination of bottom-up and top-down approaches of training modules served as interventions. A multi-method analysis with semi-structured interviews, site visits, and a questionnaire study completed the research on the initiated behavioral safety process.

CHAPTER 8
COMPLIANCE WITH SAFETY RULES: THE ROLE OF ENVIRONMENTAL STRUCTURES

Markus Schöbel

This chapter provides a framework for analyzing compliance with safety rules and procedures. The goal is to bring together and structure the disparate literature that I view as relevant to a better understanding of rule-related behavior. Rule-users' psychological transformation of codified demands in behavioral responses depends on features of three kinds of environmental structures. It is argued that information stemming from the rule, the task, and the social environment of an organization is sampled and aggregated by the rule-user; this information determines outcomes of rule-related behavior. In order to optimize compliance with safety rules in nuclear power plants, interventions should account for these features.

INTRODUCTION

In recent years the codification of safety-relevant processes has become one major approach to controlling risks in nuclear industries. A great deal of attention has been drawn not only to the standardization of technical components, but also to the development and refinement of normative systems in the domain of human factors . These kinds of intevention mainly focus on behavioral targets with differing degrees of standardization: from the safe fulfillment of work tasks to decision-making patterns in emergency situations. Moreover, concepts like safety culture (International Nuclear Safety Advisory Group [INSAG], 2002) and safety management (INSAG, 1999) provide popular frameworks for structuring human behavior at all levels of an organization. In terms of reducing and managing uncertainty, the benefits of codification are essential for organizational well-being. It is assumed that an increasing standardization of individual, group, or organizational behavior allows for a higher predictability of safe outcomes. It enables the evaluation of risk control strategies by the organization itself or by third parties (authorities, regulatory body, etc.). Additionally, the implementation of new rules or procedures mirrors the essence of (inter-) organizational learning processes by assuring that safety-relevant experiences are translated into appropriate organizational behavior.

However, many studies have shown that risk control through behavioral codification sometimes is not adequate to meet intended goals. The degree of successful control of risks associated with human factors is not yet as high as that for controlling physical risks in nuclear installations. For example, Marsden (1996) analyzed 180 incidents reported to the Institute for Nuclear Power Operations in 1985 and found that 48% of incidents attributed to human performance failures can be assigned to procedure-related failures involving deficiencies in the preparation and revision of procedures, weaknesses in the communication of procedures, and noncompliance. Similar results were obtained by Rasmussen (1980).

This chapter presents the psychological perspective on the interaction between the human actors and rules embedded in settings in which safety performance is vital. It attempts to analyze the determinants of rule-related behavior by referring to safety-relevant features of compliance situations and their impact on behavioral adaptation to normative environments. Deviations from safety rules are discussed and analyzed in a manner that shows the connection between environmental features of compliance situations and corresponding behavioral responses. In a first step, assumptions about the transformation of codified demands in behavioral responses are made.

ENVIRONMENTAL FRAMING OF COMPLIANCE SITUATIONS

Safety rules are explicit expectations of how to behave in response to a predicted situation in order to achieve a required level of safety. Hence, safety might be a property of an action belonging to a work procedure covered by the rule, or it might relate to a specific action that has to be taken in addition to work procedures (Leplat, 1998). Safety rules vary in relation to the degree to which they limit the freedom of behavioral choice. They might concern behavioral goals, define the way in which decisions about a course of action must be arrived at, or prescribe concrete actions (Hale & Swuste, 1998). In accordance with their constraining characteristics, safety rules exert a normative influence on individual behavior. In line with their guiding characteristics, they exert informational influence on individual behavior.

Safety rules pose certain demands on or guides for rule-users' regulation of behavior. In order to understand or optimize outcomes of rule-related behavior, it is necessary to analyze the adaptive match between cognitive factors (of the rule-user) and environmental factors (in relation to situational constraints) in compliance situations. Thus, it seems reasonable to seek out the subjective conditions under which explicit norms are translated into behavioral responses. Ignatov (1999) describes this process as "redefinition." It involves the internal representation of the demands of a rule and their behaviorally relevant evaluation in relation to existing situational constraints and rule-user experience. Divergences between prescribed and actual behavior are viewed as an outcome of the individual process of redefinition.

In order to structure the input or the "processing objectives" of redefining safety rules, three facets of environmental factors or "environments" are proposed. These facets coincide and interact in compliance situations. First, features of the rule environment are taken into account. They are directly linked to the organizational development and provision of rules or procedures. Second, rule-related behavior is embedded in a task environment, where various work tasks must be carried out. Objectives can be derived from the task environment, which might conflict with the safety objectives prescribed in rules. Third, influences on compliant behavior are assumed to stem from the social environment, where rule-users interact with others and elicit information about rules and their compliance with these rules.

The use of the term "environment" is twofold. On the one hand, it refers to a set of constraining conditions affecting the mind-set of a rule-user. Redefining rules involves cognitive processes that are motivated by individual needs, drives, and goals. Environments provide information that is sampled and aggregated by the rule-user. This information then permits and constrains efficient and safe operations. On the other hand, the psychological impact of environments is clearly linked to organizational behavior. Their structure results from managerial decision-making or line-management interventions. Although causal interactions between "sharp-end" and "blunt-end" factors are complex, the scope of analyzing rule-related behavior should include influencing factors that determine compliance situations. Therefore, a framework is provided that differentiates between three types of environmental features. In the following sections these environmental features and related empirical evidence are presented in more detail.

FEATURES OF THE RULE ENVIRONMENT: NORMATIVE CLARITY OF CODIFIED NORMS

If compliance with safety rules is expected, rules must be accessible for the rule-user and applicable to existing situational constraints (Leplat, 1998). Redefining the demands of rules for behavior depends largely on the normative clarity of the prescribed action. Rule-users should know when and how to act according to rules. This requisite implies that predicted and actual situational features must correspond. Mismatches can be attributed to the gestalt of a rule itself. Dien (1998) illustrated the viewpoint of designers developing applicable procedures for nuclear installations. One source of conflict is that rules are designed according to an operator model, which is often mechanistic and static. Two problems can occur. First, it is assumed that a potential rule-user has an "average" competence—the characteristics of the user in relation to his strengths and weaknesses are neglected. Second, rule-designers must develop temporal guiding procedures or rules. They have to predict action sequences susceptible to process dynamics, yet these dynamics can hardly be foreseen (e.g., defect or missing components, unavailable information). Impractical safety procedures, with instructions containing technical faults or incomplete descriptions, might be the result. Moreover, normative clarity can be challenged by contradictory safety rules that are behaviorally relevant for the same situation.

These kinds of conflicts are directly linked to the quality of the procedural infrastructure. Its functioning is characterized by a fixed hierarchy between rules (Leplat, 1998). Additionally, this infrastructure promotes the exchange between rule-user and rule-designer in order to motivate rule-users to work according to rules and, if necessary, to feed back problems with existing rules in order to refine them (Marsden, 1996).

Normative clarity is an important precondition when compliant behavior is expected. It mainly relates to the internal design of a safety rule and its relevance in relation to predicted situational constraints. However, the psychological impact on behavioral regulation in compliance situations is not exclusive. There are other factors that can constrain rule-related behavior. They lie outside the range of the rule environment and are associated with the goals that individuals develop or bring along in compliance situations.

In the following section I present the view that features of the task environment are crucial for outcomes of individual responses to codified demands.

FEATURES OF THE TASK ENVIRONMENT: THE ROLE OF CONSTRAINING TASK OBJECTIVES

Compliance situations are embedded in a work context. Safety rules accompany the fulfillment of various tasks. Hence, within work contexts the demands of safety rules interact with the task objectives that target efficiency. Carrying out both objectives requires actions that do not necessarily coincide. Potential conflicts displaying a mismatch between safety and production considerations may arise. For example, Reason et al. (1998) link this mismatch to situational rule violations that are motivated by the need to get the job done. Such violations can become routinized when they provide an easier way of working. Experimental studies on behavioral warning compliance show that time pressures significantly reduce the level of compliance (Wolgalter et al., 1998). In addition, costs in terms of behavioral efforts to comply have similar effects on warning compliance (Wolgalter et al., 1989). Both cost-related and situated factors can produce a psychological rewarding function that dominates safety concerns. On the one hand, they are directly related to functional aspects of the work task, which can be at odds with a rule. On the other hand, they trigger personal goals, such as those attained in order to optimize performance in work situations experienced as boring or monotonous.

The occasional predominance of task objectives is rooted in situational constraints, which activate corresponding cognitive processing toward behavioral decisions. In conceptualizing the cognitive processing of task objectives versus safety objectives, many authors favor a mental risk/benefit ratio, which is assumed to determine behavior in compliance situations. Zeitlin (1994, p. 173), in line with Sanders and McCormick (1992), illustrates the decision-making approach that is based on the assumption that all behavior is purposeful:

1. Safety instructions are generally correctly observed and interpreted by users.
2. If a user disregards a safety instruction, he or she has chosen to do so.
3. Although the decision to disregard the instruction may not appear rational to the product provider, there must be some benefit to the user.
4. Most disregarded instructions do not end in disaster, so disregarding instructions is a type of behavior likely to be reinforced by the benefit incurred.

Proponents of this approach suggest that behavioral responses in compliance situations are motivated by the experience of rule-users in relation to perceived risks and benefits. By means of a laboratory experiment, Zeitlin (1994) was able to identify several dimensions of mental trade-offs in compliance situations: “If a worker places high value on his or her time, convenience, self-image, status among peers, and other factors, and if he or she estimates the probability of being injured by disregarding an instruction as sufficiently low, then it is likely that the instruction will be ignored despite its clarity of presentation” (p. 179). Battmann and Klumb (1993) frame such trade-off functions by referring to the concept of “behavioral economics.” They argue that compliance with safety rules reflects an interest in behavioral optimization. As a consequence, rules that do not support individual attempts to optimize one’s own actions are more likely to be violated. In this regard, behavioral optimization is understood as a trade-off between the amount of resources gained minus the amount of resources invested.

The determination of an organizational contribution influencing a safety-consistent task environment is much more fuzzy than the creation of a well-defined rule environment. In order to enhance perceived benefits in a compliance situation, one obvious strategy is to tackle the potential risk/benefit ratios of rule-users by sanctioning violations and/or rewarding compliant behavior. This strategy can be used in the goal prioritization of an organization (Weil and Apostolakis, 2001). The crucial point is to what extent the stated goals are appropriate and acknowledged and followed by the plant personnel. Furthermore, goal prioritization is assumed to directly impact resource allocation (funding of certain programs valuing certain ideals) and time urgency (workers do not feel pressured to maintain the production schedule). However, task objectives are more flexible and involve greater degrees of freedom, especially with respect to their temporal dimension. In general, their redefining function produces greater variance of behavioral responses. Organizational efforts to prioritize goals are a prerequisite for safe operations, but they are not of themselves sufficient. Hence, Battmann and Klumb (1993) formalize task objectives, like safety rules, as local and global rules of production in order to clarify their varying impact on the shop-floor level. In this regard Reason (1990) argued that violations of safety rules “can only be described with regard to a social context in which behavior is governed by operating procedures, codes of practice and the like” (p. 195). A similar argument is provided by Lawton (1998), who stresses the importance of informal norms developed by work groups that are influenced by the culture of an organization. The following section describes the impact of social factors on compliance with safety rules.

FEATURES OF THE SOCIAL ENVIRONMENT: THE ROLE OF SOCIAL NORMS

Safety rules are developed, transmitted, and monitored within the social environment of an organization. "Social" refers to at least two meanings: rules are established and codified through interpersonal knowledge and experience, and they are redefined or embodied in people, both real and imaginary. Safety rules are not tailored for one specific person, they apply for many individuals in an organization. It therefore seems obvious that rule-users should take socially derived information about rules into account. Behavior, communicated and elicited through the information of others, is one important source about how to handle rules.

Until now safety research has focused on different aspects of the social environment in order to analyze rule-related behavior. The results of an empirical study by Simard and Marchand (1997), with 1,061 work groups from 97 manufacturing plants, emphasized the relationship between supervisors and work groups with respect to rule compliance. The two most important predictors of a work group's propensity to comply with safety rules were the cooperative work group-supervisor relationship and a participative approach to safety in supervisory management. The authors reasoned that safety compliance is higher when supervisors have some power and influence over decisions that affect the safety of their work groups and put compliance into practice in cooperation with workers.

Other authors focus on social verification processes of information about safety and their associated knowledge-building functions. For example, Rochlin (1999) assumes that safety is an emergent property of the dynamic social interaction of operators with their equipment, their environment, and each other. Weick and Roberts (1993) put forward the idea that safety is a result of the "heedful" interaction between individuals, their shared knowledge, and responsibility. They describe the active construction of partly shared situation models in a work group by means of the group interaction theory of Solomon E. Asch. The social environment serves as a reference point against which one's own actions are compared and constructed. Ignatov (1999) draws attention to implicit norms that work groups develop by themselves in order to organize their work. He provides descriptions of implicit or unwritten norms obtained through standardized interviews with control-room operators. These norms cover a broad range of reactor control-room activities. On the one hand, implicit norms strongly relate to the fulfillment of work tasks as sharing operational responsibility, passing information on to superiors, or taking into consideration different ranges of tolerance for explicit rules. On the other hand, Ignatov identifies socially oriented norms concerning self-presentation in terms of competence and self-confidence, as well as gender-specific norms ("macho" norms) about sharing emotional experience.

Like the objectives derived from the task environment, social factors influence the motivational basis of redefining safety rules. Social psychological literature reveals that individual motives are affected by other individuals in two ways, namely, normative social influences and informational social influences (Deutsch & Gerard, 1955).

Normative social influence is based on the desire to conform to the expectations of others. It is coupled with the assumption that the source of influence will respond more favorably to conformity than to deviance. The power of normative social influence is moderated to the extent to which the target of social influence disagrees with the expectations transmitted by the source of influence and the opportunities of this source to sanction the target. The latter is mainly attributed to the behavior of superiors described, for example, in groupthink theory (Janis, 1972). However, social ridicule and group rejection also form effective sanctioning mechanisms in formally symmetrical relationships (Ignatov, 1999).

Informational social influence is based on the acceptance of information from others as evidence about reality. It is coupled with the assumption that the source of influence is more correct or knowledgeable than oneself. One important precondition for the impact of informational social influence is the subjective uncertainty of the target of influence. Thus, this type of social influence is directly linked to the knowledge-based control level of human performance, where task-relevant information triggers individual problem-solving processes. In experimental studies Schöbel and Rieskamp (2002) show that when individuals ignore their own information due to the aggregation of socially derived information, rational decision-making patterns may result. According to the theory of information cascades (Bikhchandani et al., 1992), subjects show individual Bayesian updating behavior in sequential decision-making settings in which various individuals have to decide sequentially the same kind of decision under uncertainty. An informational cascade occurs when every subsequent actor, using observations about the decisions of others as a basis, makes the same rational choice independent of his own (sometimes contradicting) individual signal. Interestingly, although in an informational cascade everyone is acting rationally individually, there is the possibility that everyone is taking the wrong action. Initial inaccurate information begins chains of incorrect decisions that are not broken by the more representative signals acquired later. A reverse cascade emerges despite the fact that all individual signals in sum are more likely to generate correct decisions. It has been argued that in order to prevent erroneous behavior by many decision-makers in settings requiring safety performance (e.g., notations in monitoring sheets), individuals should decide without knowing the decisions of others. Afterwards individual decisions should be discussed and aggregated in a group context.

Organizational efforts to optimize social environments are very sparse. The aim is to establish a correspondence between social influence patterns and the demands of safety rules. In accomplishing "social" interventions, nuclear power organizations mainly focus on the concept of safety culture. Here, nuclear power plants appeal to the safety-oriented values and attitudes of its members by means of organizational policies. There are also interventions intended to shape leadership behavior through management and supervisor seminars (see Chapter 9 in this volume), reflecting group dynamic processes at work.

BEHAVIORAL REGULATION WITHIN THREE ENVIRONMENTS: THE RULE-USER PERSPECTIVE

The previous sections summarize evidence for three types of environments that have an impact on behavioral regulation in compliance situations. The impact of each type of environment was treated more or less separately from its organizational embeddedness. However, in real compliance situations these sources of information are generally available in combination. How does the rule-user go about integrating them?

One possible answer to this question emerges when one links the theory of planned behavior (Ajzen & Madden, 1986) to the features of the three environments. This theory assumes that individuals make systematic use of the information available to them. They consider the implications of their actions before they decide to engage or not to engage in a given behavior. Hence, the most important determinant of a person's behavior is behavioral intention. An individual's intention to perform a behavior is seen as a combination of three kinds of subjective considerations. These beliefs and their evaluation can be linked to the demonstrated three environments and their redefined features governing behavioral regulation in compliance situations.

First, behavior in compliance situations depends on a rule-user's perception of his or her *behavioral control*. If the normative clarity of a safety rule is low, rule-users' beliefs about controlling and performing the behavior in question are directly affected. Second, features of the task environment influence users' beliefs about the likely outcomes of the behavior (e.g., to save time, to endanger oneself or others, to draw sanctions) and their evaluation. These beliefs produce a favorable or unfavorable *attitude* toward compliant behavior. Third, intentions to comply with safety rules are influenced by the normative expectations of others (colleagues, supervisors, etc.) and the users' motivation to comply with these expectations. These beliefs result in the *subjective norm*.

In order to analyze behavioral regulation in compliance situations, many studies have utilized questionnaires based on the theory of planned behavior. As Parker et al. (1992) have shown, social and control beliefs are the strongest predictors of a behavioral intention to comply with traffic rules. Interestingly, a study by Stasson and Fishbein (1990) revealed that individual risk perception does not have a direct impact on behavioral intentions to comply with a safety rule. It only affects the degree to which individuals believe that others want them to comply. Wilpert et al. Schöbel (2002) applied the theory of planned behavior to rule-compliance in nuclear power plants. They developed scenarios for members of the operational and the maintenance personnel which depict situations in which compliance with safety rules is in question. These scenarios serve as stimuli for estimating the relative importance of the three components of the theory of planned behavior in predicting behavioral intentions to comply with safety rules. Methodological considerations prompted the assumption that the rules under examination were known to the research subjects. As a consequence, behavioral control did not have a significant impact on the examined behavioral intentions. Multiple regression analysis revealed that subjective norms and attitude are important predictors of an intention to comply. Both components together explain between 28% (not performing a renewed inspection) and 60% (postponing the inspection of a sensor) of the variance in intention, whereby subjective norms had a significantly greater impact than attitude.

The results of this study illustrate that features of the social environment play a crucial role in redefining safety rules. Although only a few scenarios were selected, organizational attempts to improve rule-related behavior should take the social dimension into account when tasks and the rule environment are updated. In the following section I present assumptions about practical improvement strategies that integrate the requirements of all three environments.

THE ORGANIZATIONAL PERSPECTIVE: KEY COMPONENTS TO IMPROVE RULE-RELATED BEHAVIOR

The proposed framework attempts to ascribe individual behavioral regulation in compliance situations to organizational strategies of promoting compliance with safety rules. As described earlier, existing interventions already capture human factor aspects in shaping compliance situations in relation to safety concerns. When one considers the empirical evidence about behavioral regulation in compliance situations, it becomes clear that individual rule-related behavior is sensitive to situational constraints created by the impact of features of the three environments. Problems with safety compliance may arise from organizational weakness in shaping compliance situations. These deficiencies are directly linked to higher organizational decision-making processes in relation to safety objectives. It can be traced back to the highly ambiguous nature of the relationship between the certainty of outcome and the quality of feedback when allocating resources for safety (Reason, 1990).

To tackle these shortcomings, nuclear industry organizations should apply holistic approaches to find a safe and efficient balance between the various impacts of the features of the three environments on rule-related behavior. Safety management approaches or safety culture interventions are efforts to account for such a merging strategy by structuring organizational behavior in relation to individual behavior in compliance situations. On the one hand, they provide frameworks for administrative control of rule-related behavior. On the other hand, they focus on the significant impact of leadership behavior on rule-related behavior at the sharp end of an organization (International Atomic Energy Agency, 1998). However, it has been argued that these concepts underemphasize the variability of rule-related behavior in relation to situational constraints. In order to achieve a sustainable optimization of compliance behavior, it is necessary to design interventions that account for all three environmental features with respect to individuals' situated actions.

Therefore, nuclear organizations should develop interventions that (a) focus on organizational contributions in shaping situational constraints stemming from the task and rule environment and (b) account for socially influenced behavior according to safety rules. These steps would enable the components of the suggested environmental framework to be analyzed through a monitoring intervention, where behavioral responses to safety rules are monitored within a "changed" social environment.

First, in order to find a balance between safety and task objectives, the actual execution of a safety rule in the prescribed situation should be monitored. This step enables the evaluation of conflicting potentials with respect to the normative clarity of the rule and task objectives stemming from real and potential work processes where rule compliance is embedded.

Second, the monitoring of rule-users' behavior should be carried out by a "rule-evaluator" who works within the same plant. On the one hand, the rule-evaluator should not belong to the work team of the rule-user, because potential social influence patterns should be considered by an outside expert. On the other hand, the rule-evaluator should be in the same hierarchical position as the rule-user in order to establish a nonhierarchical monitoring process. It is assumed that these changed circumstances of rule-related behavior facilitate the identification of influencing features from the social environment.

The proposed monitoring process should review existing safety rules or procedures. The results of such an intervention indicate potentials of redesigning safety rules in order to optimize the adaptive match between cognitive factors of the rule-user and environmental features. Thus, we should develop optimizing strategies that primarily reconsider the degree to which the monitored safety rule limits the freedom of behavioral choice in relation to the achievement of desired safety goals.

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CHAPTER 9
SAFETY CULTURE TRAINING FOR NUCLEAR MANAGEMENT AND SUPERVISORS

Babette Fahlbruch

Rapid technological developments and an ever-increasing complexity of systems necessitate increased efforts for safety on the side of technology as well as the organization. In Germany these efforts have recently been directed toward improving safety culture, particularly in high-hazard industries like the nuclear industry. The methods for improving safety culture are measurement tools—though most of these are in a developmental state—and, more recently, seminars for top-level managers and regulatory bodies. This chapter deals with a more extended intervention: the development and implementation of a three-day training course for all managers and supervisors of a German utility. A short description of the training, including training objectives and the didactic concept, is presented, and an evaluation by the participants is discussed. The training led to the intended results: it served as the starting point of organizational change in a long-term organizational development process.

INTRODUCTION

The concept of safety culture is related to the socio-technical systems approach, at least in terms of its holistic perspective. However, safety culture is characterized by two different approaches in relation to its understanding and conceptualization of culture: one is more theoretical, based on concepts of organizational culture, and the other is more practice-oriented and has developed out of the discussions following the Chernobyl accident (Wilpert, 2001). The term safety culture ranges in its understanding from cognitive characteristics of the members of an organization to a more comprehensive understanding that includes behavior not only of the members of an organization, but also of all actors in the system. Thus, safety culture serves as a kind of Trojan horse to introduce human factors in safety-oriented improvements that aim to redress the nuclear industry's traditional orientation toward technology (Fahlbruch & Wilpert, 2000).

Acommon feature of the nuclear industry is the high level of importance placed on safety-related issues (Rochlin & Meier, 1994); the nuclear industry in Germany claims to have safety standards above even the international average. "This safety standard was reached because all parties concerned (producers, utilities, regulatory bodies, expert and research organizations) conceded safety an adequate importance" (Reaktor-Sicherheitskommission, 1997). Recently, however, the measurement and improvement of safety culture have been receiving an increasing amount of attention in nuclear plants. Thus, one German utility asked the Forschungsstelle Systemsicherheit (FSS, or "Research Center System Safety" at the Berlin University of Technology) to develop and run a safety culture training entitled "The Role of Humans for Safety and Reliability in the Nuclear Industry" for their managers and supervisors, that is, for individuals with executive duties.

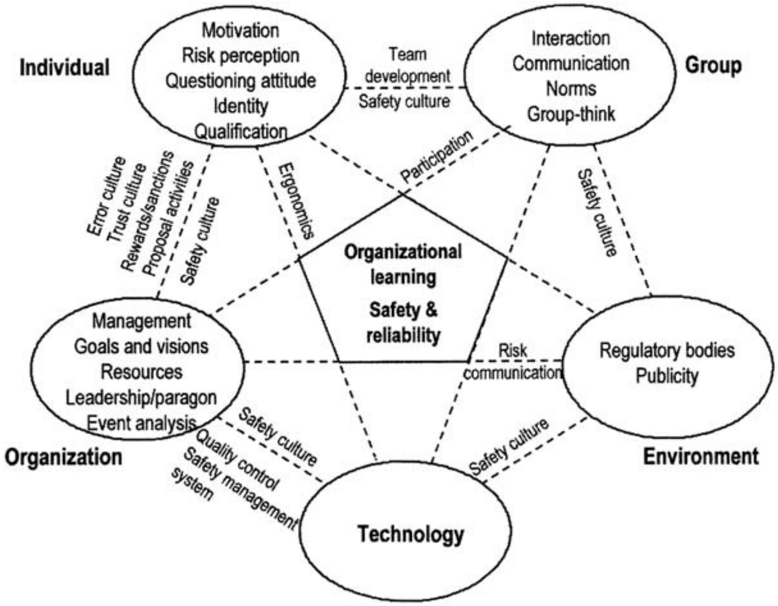

Figure 9.1 Socio-technical systems framework for the development of a training course (based on Becker et al., 1995).

THE TRAINING

Theoretical background

The theoretical background for the development was the socio-technical systems approach adopted for the nuclear industry (Becker et al., 1995) as well as Schein's approach for analyzing organizational culture (Schein, 1985). A model was developed in which five subsystems of the nuclear industry—the individual, the team, the organization, the extra-organizational environment, and technology—and their interrelations make up the framework for factors identified as crucial for the safety culture of an organization. For instance, for the individual the factors motivation, risk perception, a questioning attitude, professional identity, and qualifications were seen to be important, as were the factors of the interface with the organization, such as an error culture, a trust culture, or an incentive system. Figure 9.1 shows the theoretical components by way of a topology of relevant subsystems and their interrelations.

Training objectives

A workshop with top-level management identified factors to be included in the training course. On the basis of these factors an initial concept for the training course and a training guideline were developed. A pilot training course was then run. The following four objectives were identified for the training course overall:

1. A questioning attitude (International Nuclear Safety Advisory Group [INSAG], 1991) was defined as a constant and critical testing of one's own actions and as the permanent search for improvement of technical and social procedures in relation to the plant's safety and reliability.

2. Systemic thinking (Dörner, 1989; Senge, 1996) characterizes an understanding of the high interdependence of social and technical connections within a plant and leads to a conscious awareness of the potential consequences of one's actions.
3. The function of managers and supervisors as role models refers to managers' consciousness and commitment to act as a model (Bandura, 1976) for adequate safety-oriented performance.
4. Professional identity relates to self-confidence in one's perceived responsibility for one's own performance (Seliger, 1997) and an open, exchange-oriented attitude that can respond to information demands and worries of the public (Covello et al., 1988).

Description of the training

To meet the overall training objectives and the factors identified in collaboration with the utility's top-level management, the training had to cover the five topics listed in Table 9.1. These topics were treated in succession in the training course.

Table 9.1 Training course program

Day	Topic
First day, evening	Goals and vision of the organization
Second day, morning	Main issues of safety and reliability: understanding of culture and safety culture
Second day, afternoon	Measuring safety culture and organizational experience with safety culture
Third day, morning	Improving safety culture
	- within the organization
	- in interaction with the public
Third day, afternoon	Leadership as a driver of change: conclusion, reflection, and future planning

Goals and vision of the organization

This part of the training demonstrated the importance of an organization's goals and perspectives for safety and reliability. A top-level manager of the utility started the training course with a "pep talk" on the organization's goals and visions. This opening was in line with statements of an advisory group of the International Atomic Energy Agency (INSAG, 1991), which make clear that the explicit naming of safety-oriented goals by top-level management is indispensable in the creation of a safety culture. After the pep talk an overview of the training course was provided, and participants were asked what they expected from the training.

Main issues of safety and reliability: Understanding culture and safety culture

The first part mainly served to establish a common understanding of crucial terms: definitions and developments in the field of safety were explained by the trainers, and characteristics of the nuclear industry were discussed. Safety culture concepts were then presented (INSAG, 1991; Schein, 1985) and discussed in relation to the meaning of culture. The difference between safety culture and operational safety was also discussed.

Measuring safety culture and organizational experience with safety culture

The problems and difficulties associated with the measurement and evaluation of safety culture were the central topic during this part of the training. Various approaches to measurement were presented and discussed. The participants developed indicators in a simulation exercise that could be used for self-assessment of their nuclear plants.

Influencing safety culture within the organization and in interaction with the public

This part of the training focused on ways to influence and maintain a positive safety culture. With respect to improvement within the organization itself, the main issues worked through were errors, error management, and trust, with the participants developing a model for the treatment of errors. With respect to the improvement of safety culture in interaction with the public, principles of risk perception and risk communication (Fischhoff, 1995) were explained, particularly in relation to the present status of the nuclear industry in Germany. The participants discussed mixed and misleading messages, such as those arising from the use of scientific understandings of terms such as risk, safety, and conservative assessments; these often differ from common understandings and thus lead to misunderstandings (Jardine & Hrudey, 1997). The participants also developed a risk communication strategy for different target groups of the public (e.g., journalists, politicians, teachers).

Leadership as a driver of change

After the presentation of a short summary on leadership models, the discussion during this last training segment focused on the central role of managers and supervisors—the participants of the training course—in initiating processes of change related to safety culture. The participants generated opportunities for optimizing their or the organization's performance through various leadership activities. The training ended with a comparison of participants' expectations and their evaluation of the training course. Before participants departed, each was asked to decide privately what they intended to change in their daily work activities (Lewin, 1947; Misumi, 1985). This decision remained private and was not divulged to the others. This concept of group decision was developed by Lewin (1947).

After an extended group discussion, which set group norms, individuals make a private decision. The theory behind this approach is that changes in behavior last longer when group norms are changed, for which the group discussion serves compared to attitudinal changes on the individual level. The decision serves as building of intentions. The correlation between intention (the decision builds an intention) and subsequent behavior is higher than the correlation between attitudes and behavior. Therefore, the chance of a change in behavior is greater after this procedure.

DIDACTIC PRINCIPLES

The didactic concept of the training adopted a successive phase model, starting with an input phase, followed by an interaction phase, and ending with a plenary reflection phase. The interaction phase included work in small groups as well as self-analysis by the participants. Each of the five topics was planned in accordance with these didactic principles, with the exception of the first, goals and vision of the organization, which always was presented as a pep talk by a top-level manager of the utility. The training ended with an overall reflection phase that took into account the goals and vision of the organization, as well as the participants' expectations from the first part of the training, and thereby reached closure in the sense of a complete gestalt. All participants received copies from the input phases, worksheets for the interaction phases, and a reference list with further readings.

EVALUATION OF THE TRAINING

Of the 24 trainings that were given, 14 of them, with a total of 196 participants, were used for the evaluation. The evaluation was conducted in several steps:

1. The participants gave an overall evaluation of the three days by anonymously placing a sign on a poster evaluating the dimensions process (structure and quality of the training) and the results (what the participants gained). Figure 9.2 gives an overview of the direct evaluation of the 14 training courses.
2. The participants received a questionnaire for a specific evaluation tailored to personal gains and practical relevance. The questionnaire was mailed back to the FSS after participants had returned to their plants. The questionnaire consisted of an overall assessment and topic-specific assessments. There was also space for personal remarks. Altogether 142 questionnaires were returned (72.45% return rate). The training was thought to be interesting and important, with small preferences for "influencing safety culture within the organization," "influencing safety culture in interaction with the public," and "leadership as a driver for change" indicated.

Examples for additional remarks on the training were "content and didactics are good," "training should be repeated regularly for management," "more time for discussion and exchange—should be extended," and "a successful training," which show that the participants even considered an extension or continuation of the training. The participants were also satisfied with their personal gains and gave remarks like "stimulates self-reflection," "with the evaluation of another plant you think automatically of your own workplace: good procedure," and "insight and confirmation that safety culture must be lived." With respect to practical relevance, remarks like the following were given: "a stimulating change of received practices," "results of the working groups are a good basis for the evaluation of progress after about two years," "respectful treatment of partners in communication will be given more attention in future," and "only the participants themselves can reflect on their own practices." The utility itself formally reported to the regulatory body that the training was very successful.

3. The results of the direct evaluation and questionnaire, as well as the reflection of the trainers, were discussed in a workshop with top-level management. It was agreed that the training was a success. The composition of participants—from three plants, from different hierarchical levels, and from different departments—was judged positively. The interactive training course brought about positive group-dynamic processes that led to a high level of interest among the participants, to lively discussions, and to very productive group performance. For instance, more than 170 suggestions for the optimization of leadership performance were generated. It was agreed to evaluate the implemented changes, which necessitated the development of another questionnaire.
4. This questionnaire was distributed to the participants 15 to 24 months after the training. Because of turnover among personnel, only 180 questionnaires could be sent out, of which 88 (48.89%) were returned. More than 50% of the participants had observed changes after the training. Figure 9.3 shows the areas of change as a consequence of the training course, as perceived by training participants.
5. In a second workshop with top-level management, feedback on the evaluation and on the assessed impact was discussed. Overall, the implemented changes were judged as exceeding expectations: safety

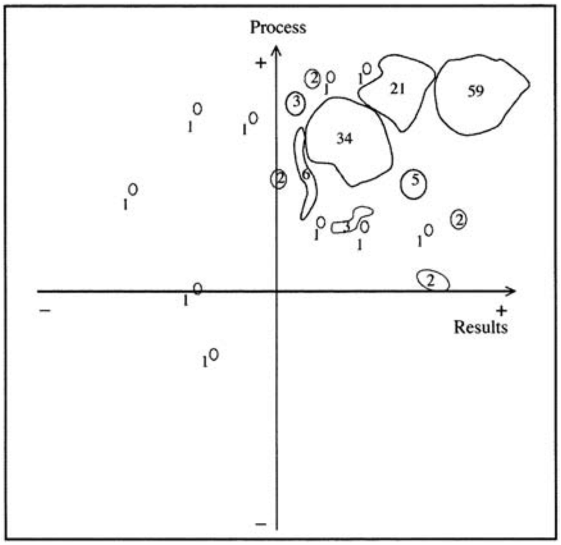

Figure 9.2 Overall evaluation (N=196 from 14 trainings; numbers indicate frequency of individual evaluations).

culture is now seen as a relevant topic within the organization, information exchange has increased, and a new understanding of leadership has developed. Last but not least, the objectives of the training were fulfilled for the majority of participants.

DISCUSSION

On the basis of our experience with the training course, we developed an intervention concept for the introduction and sustained intensification of safety culture based on the following assumption. The intensification of safety culture is a long-term process of organizational development. Organizational development itself aims at a planned, effective, and sustained change of patterns of behavior, employee attitudes and skills, organizational and communication structures, and structural rules in a broader sense. Therefore, on all levels of the organization learning processes should be started, and these processes must be supported by adequate instruments and methods. Top-level management must give clear and trustworthy support to the organization's goals. Thus, our concept includes a close linking of various approaches and instruments for different target groups or different hierarchical levels, such as variable starting points and different directions of procedure—top-down, bottom-up, and middle-both directions. Furthermore, three successive phases were conceptualized: the initiation phase, the implementation phase, and the evaluation phase. Figure 9.4 gives an overview of the conceptual scheme for introducing and maintaining an effective safety culture. An organizational development process based on this conceptual scheme has been introduced and is being implemented in one plant.

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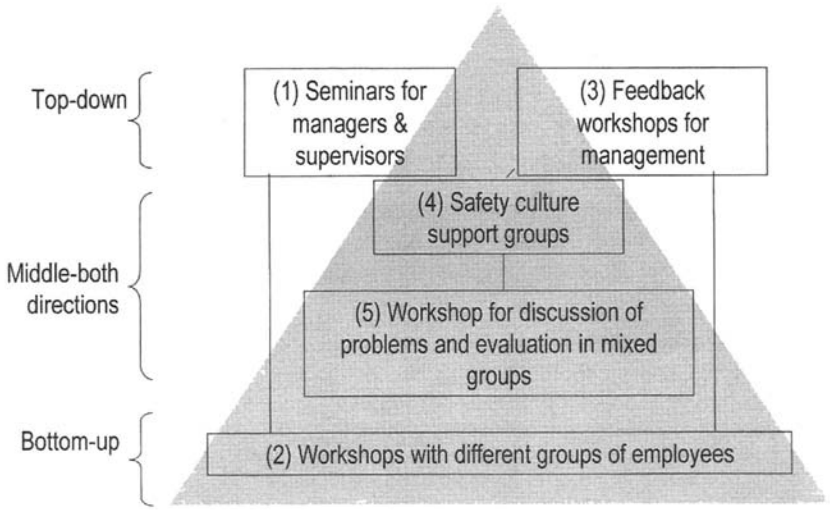

Figure 9.4 Conceptual scheme for sustained intensification of safety culture.

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CHAPTER 10
AN ANALYSIS OF THE JCO CRITICALITY ACCIDENT: LESSONS LEARNED FOR SAFETY DESIGN AND MANAGEMENT

Fumiya Tanabe and Yukichi Yamaguchi

The nuclear criticality accident in Tokaimura, Japan, was analyzed using a framework based on cognitive systems engineering. Analyses were made from the point of view of both the system and the actors, which include analyses in terms of the safety boundaries against criticality accidents. We found that incorrect mental models about the work system played a critical role in bringing on the accident and that such models were formed and influenced through several factors, such as, in terms of criticality safety, a poor system of education and training, lack of information in procedures and instructions, and no warning signs at workplaces. From these results we derived a set of immediate countermeasures and generalized lessons in order to prevent such an accident in the future.

INTRODUCTION

The criticality accident at JCO Company Ltd. in Tokaimura, Japan, on September 30, 1999, was very serious, resulting in two worker fatalities and a wide range of social consequences. The direct cause of the accident was that workers had poured uranium solution exceeding the critical mass limit into the precipitation tank (Nuclear Safety Commission, 1999). Usually the prevention of nuclear criticality accidents is ensured through at least three different measures: limiting fissile uranium (^{235}U) mass, establishing geometrical control (through favorable geometry), and limiting the chemical concentration of fissile uranium. For each process of the production system considered, the double criticality control with mass and geometry control was imposed by the regulatory body in order to strengthen safety measures.

In the JCO accident, however, the workers took an action that violated the conditions imposed in accordance with these measures, without knowing about the measures against accidents or the consequences of their action. They poured uranyl nitrate solution containing 16.6 kg of 18.8%-enriched uranium into a precipitation tank for which only 2.4 kg-U was allowed as the maximum per-unit component within a single batch. The precipitation tank had not been designed according to favorable geometry principles. Moreover, the tasks the workers were conducting at the time were the purification of material triuranium octoxide (U_3O_8) powder, the production of uranyl nitrate ($UO_2(NO_3)_2$) solution with a concentration of 370 g-U/1, and the homogenization of over one lot of 40 liters (15 kg-U). The accident occurred during the process of homogenizing uranyl nitrate solution through use of the precipitation tank. The workers themselves had come up with the idea of utilizing the precipitation tank to homogenize uranyl nitrate solution. They had been provided with a set of written instructions and procedures for homogenizing the solution, which directed them to utilize the pure uranyl nitrate solution storage tank, a container that had been properly designed according to principles of favorable geometry. In order to uncover the underlying causes and establish preventive measures against such an accident in future, a detailed analysis of the data related to the accident was carried out.

FRAMEWORK USED FOR THE ANALYSIS

The analysis was fundamentally carried out from the perspective of both the system and the actors (Tanabe et al., 1991), the framework of which is based on the cognitive systems engineering approach (Rasmussen et al., 1994). From the system viewpoint, the functional structure of the work system and the system requirements in terms of the goal to be achieved were examined. From the viewpoint of the actors, we examined how they perceived the functioning and situation of the system.

Through our analysis from the system viewpoint we identified the functional structure of the work system: namely, the work objective, constraints in achieving this objective, necessary functions, task sequence, and the system's physical structure. The constraints to be characterized are those related to safety, economic constraints from competition, and legal enforcement.

Through our analysis from the perspective of the actors, we examined how the situation was perceived by the actors, particularly in terms of safety boundaries, the actors' mental models about the system, and evidence about how these mental models were formed and shaped over time. In order to gain these insights we investigated characteristics of the training and education received by the actors as well as their work experiences.

ANALYSIS OF THE PRODUCTION SYSTEM

Production system licensed in 1984

In 1984, JCO received a license from the Japanese government nuclear safety regulatory body, allowing the production system facility to produce uranium dioxide powder or uranyl nitrate solution with an enrichment level of less than 20%. These products were to be utilized for fuel rods of Joyo, an experimental fast breeder reactor. As shown in Figure 10.1, the production process for the product solution of uranyl nitrate consisted of two parts. The first part entailed uranium oxide purification, which involved the processes of dissolution of triuranium octoxide (U_3O_8) powder, solvent extraction, precipitation, and calcination. After the process of uranium oxide purification, the second part was for producing the product solution of uranyl nitrate, which consisted of redissolution and bottling processes. It should be noted that the homogenization process had not been taken into account at that time. Although the pure uranyl nitrate solution storage tank was connected through pipes with the dissolving tank, it was intended to provide not for homogenization, but for the bypassing of the extraction column or for storage of a product just before bottling. Our analysis has revealed the need and importance of the storage function during the various processes for maintaining the flexibility of the workflow (Tanabe & Yamaguchi, 2001b).

Major modification of the production system and workflow leading to the accident

From the commencement of the production of the product solution of uranyl nitrate in 1986 to the accident in 1999, the production system and workflow had been modified four times. The last modification resulted in the criticality accident.

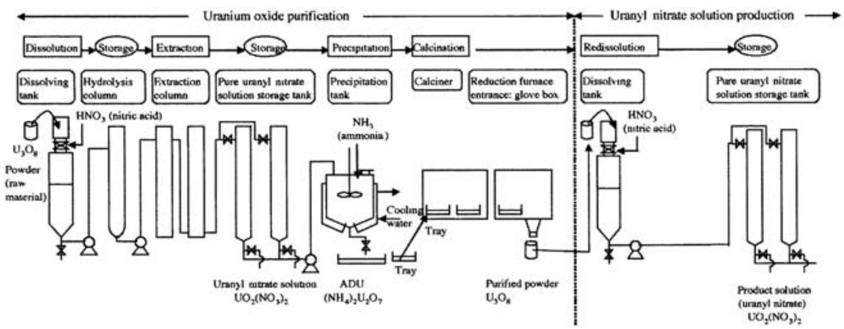

Figure 10.1 JCO uranyl nitrate solution production process licensed in 1984.

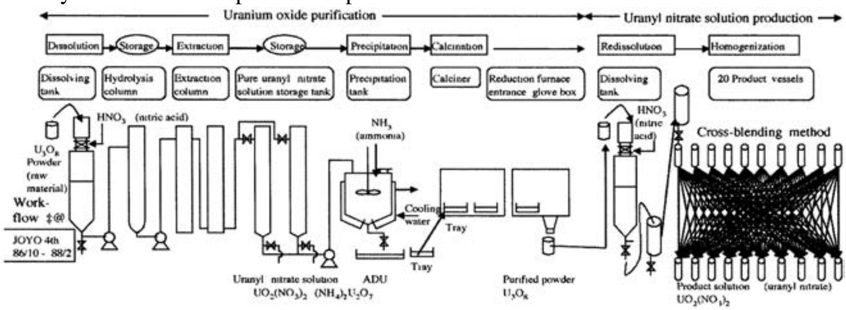

Figure 10.2 JCO uranyl nitrate solution production process and workflow (1) in Joyo fourth campaign (1986– 1988).

Workflow (1) from October 1986 through February 1988

Before the production of uranyl nitrate solution began in October 1986, a new objective was set by the client: to homogenize uranyl nitrate solution over one lot of 40 liters (15 kg-U), which required processing seven batches of 2.4 kg-U. In order to satisfy the new requirement, a cross-blending method utilizing 20 product vessels was proposed and implemented by JCO. Figure 10.2 depicts the overall production system and workflow, Figure 10.6 the detailed workflow in the redissolution and homogenization process. The cross-blending method of the homogenization process required 10x10 times of measuring precisely 0.4 liters of uranyl nitrate and transferring it from product vessels to other product vessels. The process might have exposed workers to a high risk of chemical hazard due to their direct contact with liquid or vapor from the toxic nitric acid and uranyl nitrate. The process also introduced the burden of a high workload. Workers therefore wished to and sought to improve such stressful work conditions. It should be noted that beside the occupational radiation health hazard of a criticality accident, internal exposure through the inhalation of uranium oxide powder is also a key concern. However, the risk it poses is rather small if one is equipped with a mask.

Workflow (2) from January 1993 through June 1993.

In 1993 an SUS (stainless steel) vessel was introduced in the redissolution process, replacing the dissolving tank in order to make the process more efficient. The procedure of the cross-blending method for homogenization was also changed. Namely, uranyl nitrate solution was transferred directly from the SUS vessel into 10 product vessels, without first transferring them into another, intermediate set of 10 product vessels as in the case of workflow (1) (see Figures 10.3 and 10.7).

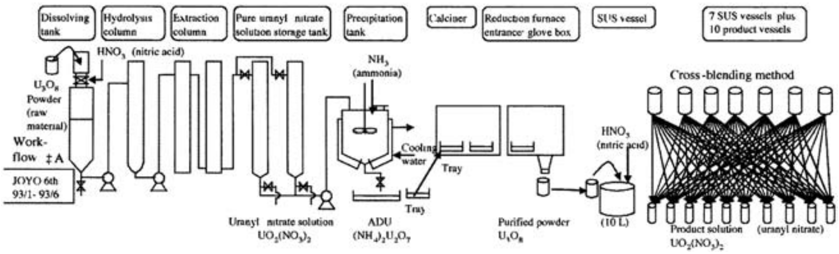

Figure 10.3 JCO uranyl nitrate solution production process and workflow (2) in Joyo sixth campaign (1993).

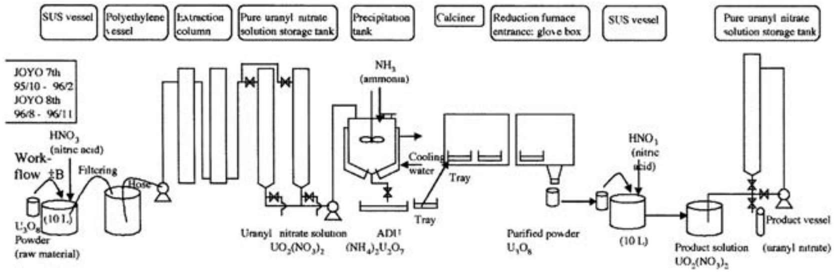

Figure 10.4 JCO uranyl nitrate solution production process and workflow (3) in seventh and eighth campaigns (1995–1996).

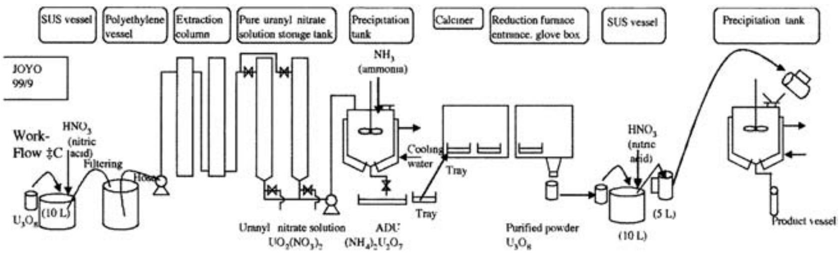

Figure 10.5 JCO uranyl nitrate solution production process and workflow (4) in 1999.

Workflow (3) from October 1995 through November 1996

In 1995 the pure uranyl nitrate solution storage tank was utilized for the homogenization process, replacing the cross-blending method (Figures 10.4 and 10.8). This change was intended to bring about greater efficiency, a lighter workload, and less occupational risk of chemical hazard. The SUS vessel was also utilized for the dissolution process in the uranium oxide purification process.

Workflow (4) in September 1999

The accident occurred during workflow (4). The workers began to utilize the precipitation tank for the homogenization process, thereby replacing use of the pure uranyl nitrate solution storage tank (see Figures 10.5 and 10.9).

The change in productive efficiency is illustrated in qualitative terms in Figure 10.10. The efficiency seems to have increased with modification of the production system and workflow. Figure 10.11 depicts the change in workload, occupational health hazard from chemicals, and difficulty in handling.

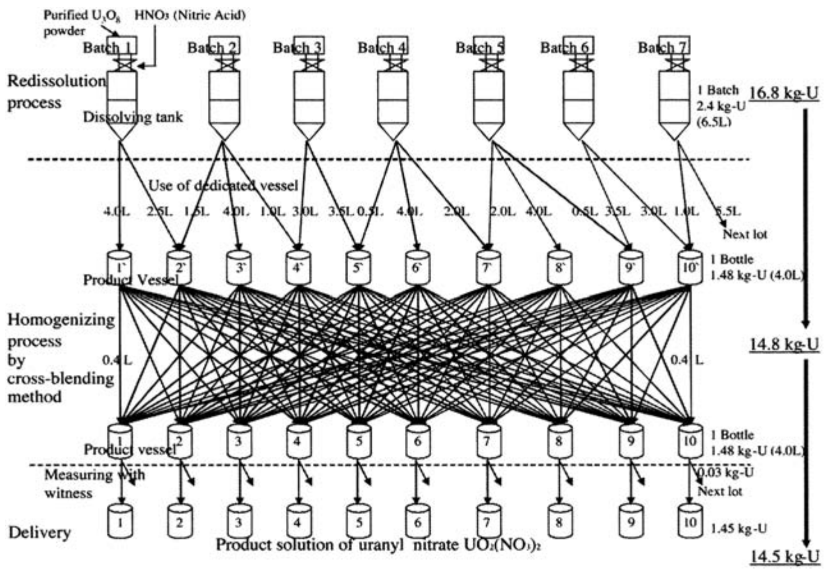

Figure 10.6 Detailed procedure in redissolution and homogenization process in workflow (1).

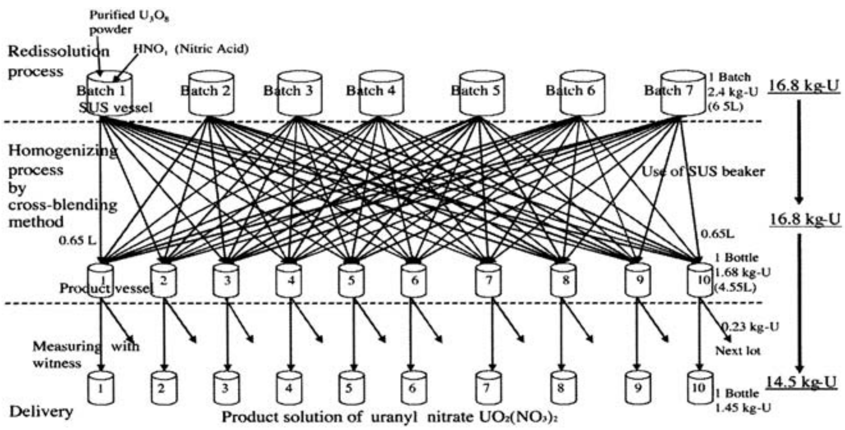

Figure 10.7 Detailed procedure in redissolution and homogenization process in workflow (2).

To summarize the above analysis, the cross-blending method for homogenization introduced the burden of a high workload and a high occupational health hazard from chemicals. It seems reasonable for the workers to wish to improve such a stressful situation. The characteristic drive of this modification process could be viewed as a process in which the conflicts between the various constraints in meeting the work objective had been resolved through weakening the safety requirements related to criticality. Of all the modifications carried out, that of utilizing the pure uranyl storage tank for homogenization was the most serious error in that it degraded the double critical control strategy with mass and geometrical control into a single critical control strategy of geometrical control.

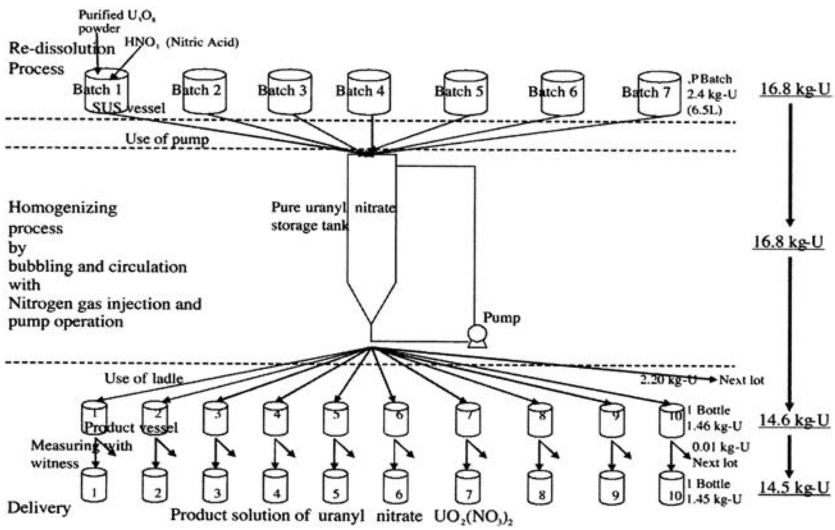

Figure 10.8 Detailed procedure in redissolution and homogenization process in workflow (3).

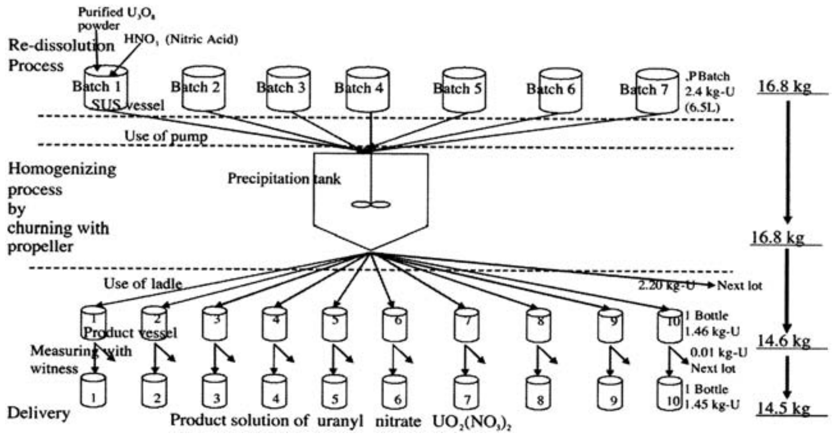

Figure 10.9 Detailed procedure in redissolution and homogenization process in workflow (4).

ANALYSIS OF SITUATION IN TERMS OF CRITICALITY SAFETY BOUNDARIES

In order to investigate the actual safety situation in the production process and workflow, the work records corresponding to each workflow were analyzed. In the analysis, the work record for each batch of uranium oxide was summarized graphically along a time line, the number of batch of uranium within each process was identified, and a typical trajectory of batch control of uranium in each workflow was made (Tanabe & Yamaguchi, 200 1a). The results are shown in Figure 10.12 in comparison with the following four types of criticality safety boundaries.

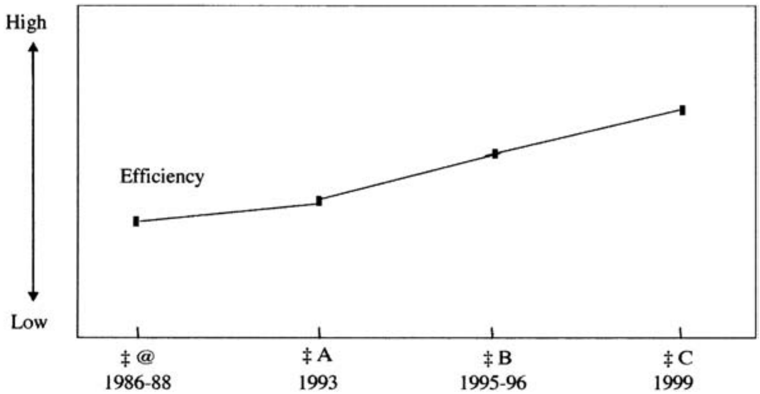

Figure 10.10 Characteristics of workflow modifications in uranyl nitrate production process from the viewpoint of productive efficiency.

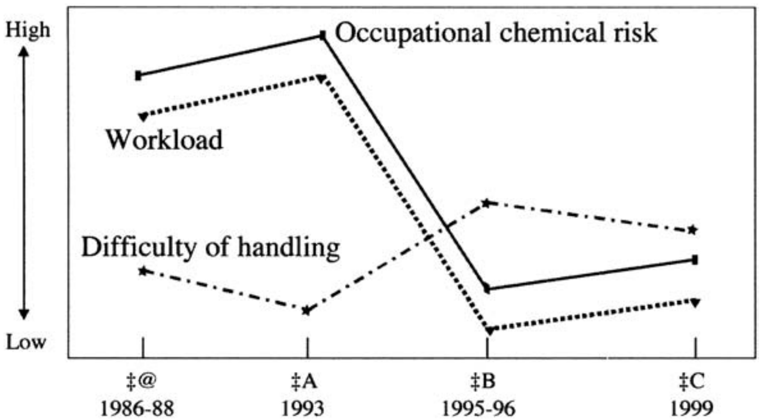

Figure 10.11 Characteristics of workflow modifications in uranyl nitrate production process from the viewpoint of occupational risk, workload, and difficulty in handling.

Criticality safety boundaries

There are four types of criticality safety boundaries: one-batch control from dissolution through the precipitation process, unit mass control per batch, critical mass, and favorable geometry. One-batch control from dissolution through the precipitation process is a regulatory requirement to limit the total mass of 18. 8%-enriched uranium, which is not to exceed 2.4 kg-U within equipment from dissolution through precipitation. Unit mass control per batch is also a regulatory requirement to limit the mass of 18.8%-enriched uranium, not to exceed 2.4 kg-U within any equipment in the production process.

The safety boundary of critical mass is a functional requirement to prevent exceeding the subcritical limit for mass. The subcritical limit for mass is influenced by shape, neutron reflection, chemical concentration of fissile uranium (^{235}U), and enrichment. The regulatory required mass limit of 2.4 kg-U takes account of the safety margin of 2.3 on the minimum of the subcritical limit for mass, which is determined by assuming spherical shape, full neutron reflection, chemical concentration of 60 g-^{235}U/l, and 20%, enrichment. Finally, favorable geometry is a functional requirement for geometry, not to exceed the diameter of a tank or depth

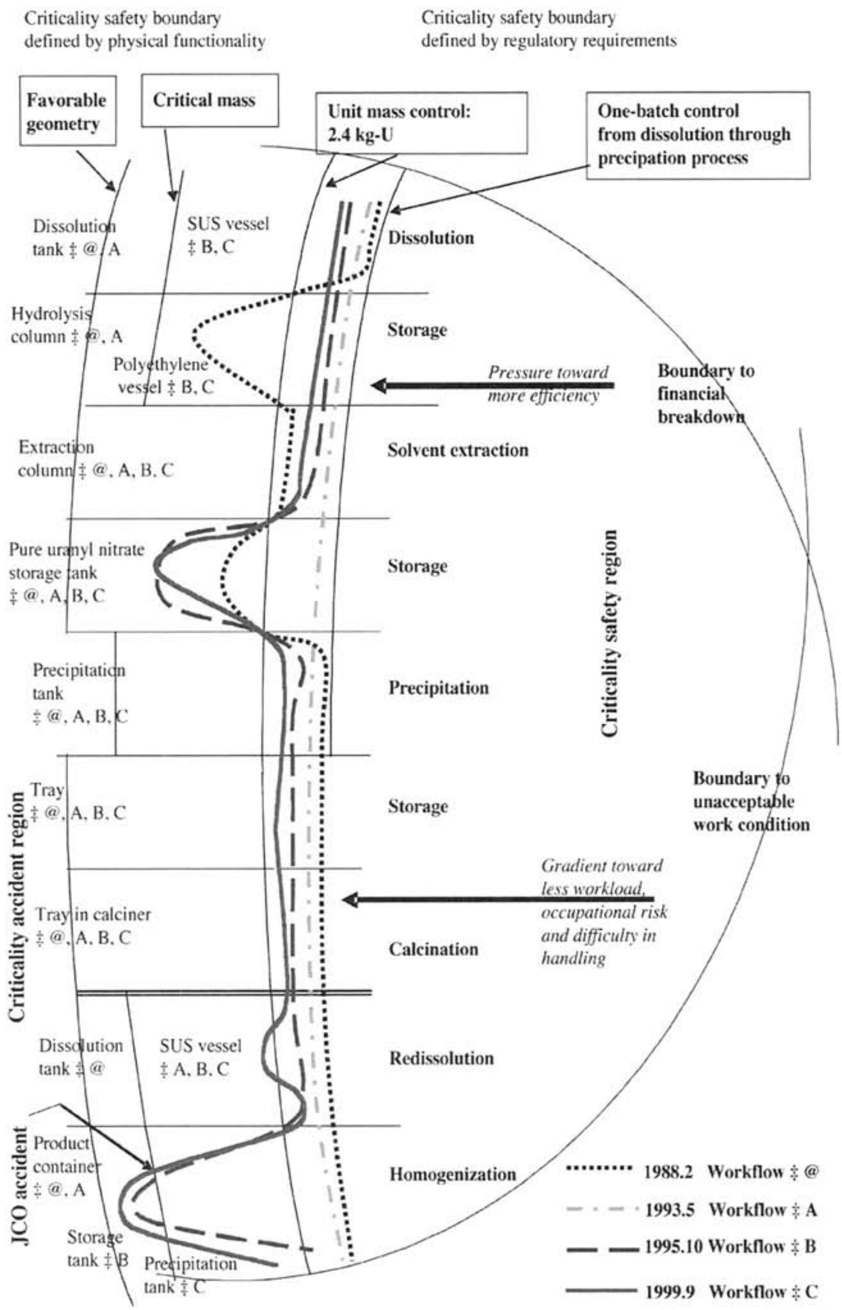

Figure 10.12 Trajectories of batch control of uranium in workflow in comparison with criticality safety boundaries.

of a tray. As long as a favorable geometry is adopted, a system can be kept subcritical with any amount of uranium.

Result of analysis

The result of the analysis is shown in Figure 10.12. Since an early stage of uranyl nitrate production (1988), the regulatory requirement of one-batch control for the whole process from dissolution through precipitation had never been satisfied. The regulatory requirement of one-batch control for each process (equipment) also had not been satisfied since 1988, with the exception of 1993. The exceptional behavior in 1993, with a return to safer practices, might have been intended to reflect a kind of safety campaign with the establishment of a crisis management committee within JCO.

Perception of the criticality safety boundaries

The workers had not perceived either regulatory safety boundaries or functional safety boundaries because of their poor training in and complete lack of information on criticality safety. Inadequacies with regard to the latter included a lack of warning signs for each piece of equipment and a lack of information on criticality safety in written procedures and instructions. Under these circumstances, the workers' mental models about the pure uranyl nitrate storage tank were shaped into an inappropriate model accounting only for its productive function (homogenizing function) and entirely disregarding its safety function (criticality prevention function). The workers did not recognize that they had violated the regulatory safety boundaries and were going to violate the functional safety boundaries.

Management apparently had known about the existence of both regulatory and functional safety boundaries, because they had taken part in applying for the license for the facility and in formulating the in-house nuclear criticality control criteria. However, in actual practice they had not respected the regulatory requirements. They might have thought that the violations did not matter for actual safety as long as they were within the functional safety boundary.

IMMEDIATE COUNTERMEASURES

Drawing from our analysis of the accident, three countermeasures have been identified which should prevent the recurrence of such an accident: education and training, use of a warning sign and warning icon, and an information system for monitoring the system state. First, it is essential to create and implement education and training methods for enhancing actors' awareness both of the potentiality of a criticality accident and of safety boundaries. These efforts would include the actors' participation in some kind of criticality-related experiment and exercises utilizing a computer simulation program for criticality phenomena. Another important measure is to increase the risk perception of actors by introducing a warning icon at the entrance of the facility and a warning sign for each piece of equipment (Laughery & Wogalter, 1997). Third, the implementation of an information system to support actors in monitoring and predicting the system state is imperative. With such an information system, actors could understand the system state in terms of the safety boundary and could predict the effect of possible actions. Furthermore, the regular and open availability of such information to the actors would support them in developing correct mental models.

GENERALIZED LESSONS LEARNED FOR SAFETY DESIGN AND MANAGEMENT

As the preceding sections have shown, the complete lack of worker awareness of the risks of a criticality accident and the criticality safety boundaries played a crucial role in the occurrence of the accident. How did such a situation come about?

We can identify risky management attitudes in reliance on the notion that safety as well as production efficiency and quality can be maintained as long as workers obey the step-by-step procedure. According to this approach, the procedures and instructions prepared for workers must be established by having experts in planning and design carefully examine the functional structures and various constraints. This approach is a traditional and common strategy for maintaining safety. The JCO accident points to a failure of such traditional strategies. In their actual work conditions, workers may face situations and difficulties that the experts could not take into account in advance. Therefore, in such a dynamic environment, workers sometimes need to design a system ad hoc in order to adapt to new situational demands. However, workers' mental models, on which the new design is based, may not be appropriate, because the traditional approach neither encourages nor supports workers' deep understanding of the system functional structure. This development implies the need for a new approach that supports workers in acquiring intellectual competence with an appropriate mental model.

A promising approach to meet these needs is an innovative integral human-work interface approach, which would offer a function- and boundary-oriented interface, procedures oriented to task goals, and function- and theory-oriented education and training (Tanabe & Yamaguchi, 2002). The ecological human-machine interface might function as the core component of this approach (Yamaguchi & Tanabe, 2000).

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CHAPTER 11
SAFETY MANAGEMENT IN NUCLEAR OPERATIONS: RECENT OBSERVATIONS FROM A GERMAN PERSPECTIVE

Gerhard Becker

This chapter analyzes relevant aspects of the German regulatory framework and raises the question of whether German legislation places the central responsibility for safety clearly enough on company executives. Weaknesses in this area, the application of current management methods to reduce costs in large utilities, and weaknesses in plant-internal safety management are seen as contributing factors to recent events, and these weak points are discussed further in the chapter. Findings from special audits and inspections in a number of nuclear power plants and the analysis of past events in one of the plants serve as the basis for this discussion. It is argued that the development of an indicator-based safety management system should not focus only on plant-internal processes. Instead, it seems essential to emphasize the role of upper management of the licensee as a part of the safety management system.

INTRODUCTION

A number of incidents in different nuclear power plants received considerable coverage in the media and raised doubts about the efficiency of safety management in nuclear power plants in Germany. The Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit [BMU]) published a press release (BMU, 2002) in which nuclear operators were urged to implement a *qualified safety management system* that is able, as a preventive measure, to avoid shortcomings in the operational organization of nuclear power plant as well as errors by plant personnel. Furthermore, on behalf of the BMU the state regulatory authorities for nuclear plants in Germany distributed a questionnaire on safety management in the spring of 2002 to all nuclear operators (BMU, 200 1b). Safety management is now the most frequently cited factor when human activity has contributed to an actual incident in a nuclear power plant.

Not long ago various types of "human-error events" were attributed to poor "safety culture." This perspective seems to be less prominent these days—perhaps because the exact meaning of the term is difficult to grasp, as reactor safety experts have admitted (Internationale Länderkommission Kerntechnik, 2002). Instead, qualified safety management systems seem to be the new topic at hand and are even treated as a "super weapon" against human errors, which are discussed everywhere today. The reflections on aspects of safety management in this chapter are based on the experience gained from event analyses and inspections in nuclear power plants in Germany, as well as from the application of quality management systems within the industry.

FROM SAFETY CULTURE TO SAFETY MANAGEMENT

The term safety culture has received increasing attention in the nuclear community over the last decade, as a consequence of the Chernobyl disaster. However, ongoing consideration of the various dimensions of safety culture has revealed that the attitudinal dimension of safety culture can only be enhanced on the basis of sound and systematic safety management. This circumstance seems to have been taken for granted during the first phase of the safety culture debate. For example, the International Nuclear Safety Advisory Group (INSAG) published its basic report on safety culture back in 1991 (INSAG, 1991), yet it was not until 1999 that the advisory group took up safety management as a topic (INSAG, 1999). The introduction to the latter report maintains that organizations with a strong safety culture will have an effective safety management system, with the support and ownership of all staff. Furthermore, the International Atomic Energy Agency (IAEA) first published its requirements and guidelines for the safety management of operations no earlier than 2000 (IAEA, 2000, 2001).

Goal-directed legislation

It may be informative to trace the origin of the concept leading to the demand for a safety management system. The roots can be found in the United Kingdom and in earlier Scandinavian legislation. The recommendations of the 1972 Robens Report marked the beginning of radical changes in the approach to the regulation of safety (Hopkins & Hale, 2002). It led to the "Health and Safety at Work Act 1974," which specifies safety goals rather than prescriptive, detailed technical standards, and which places a fundamental duty on employers to ensure, as far as reasonably practical, the health and welfare of their employees. The nuclear safety legislation in the United Kingdom is based on this modern regulatory system introduced by the 1974 Health and Safety Act (Williams et al., 1995). Many countries have now adopted the principle of goal-based legislation for nuclear safety; the policy of the Nuclear Regulatory Commission in the United States has also shifted toward this approach.

One consequence of this approach is the focus of authorities, such as the Nuclear Installations Inspectorate of the Health and Safety Executive in the United Kingdom, on assessing safety management processes rather than on checking the fulfillment of safety standards. It is now commonly held that successful safety management requires a systematic approach or model—a safety management system. This requirement to implement a management system is now included in international standards for quality management and environmental management, among others, and it also has been incorporated in the European Union's Seveso II Directive (Council Directive 96/82/EC, 1996).

The German situation

The German nuclear safety approach has evolved over the years and combines traditional prescriptive regulations with intensive inspections by independent organizations such as the Technical Inspection Association (Technische Überwachungs-Verein, or TÜV). Meanwhile, the approach, which was developed on the basis of the German Atomic Act of 1959, has reached a stage in which numerous ordinances and a large number of nuclear standards (rules from the Kerntechnischer Ausschuss, or "Nuclear Safety Standards Commission") specify the nuclear safety requirements in considerable detail. The web of requirements has become very complex; a revised approach, now in preparation, aims to reduce the number of rules from the Nuclear Safety Standards Commission. Only seven basic rules defining relatively more general safety principles shall replace the numerous detailed prescriptive rules.

The nuclear operators have developed their operational practices over the course of years within this web of detailed nuclear safety requirements. They responded with some surprise when requested to “develop a qualified safety management after all” (BMU, 2002) and referred to the federal government’s report under the Convention on Nuclear Safety (BMU, 200 1a), which attests that the nuclear power plants in Germany operate at an excellent level of safety (Weihe & Pamme, 2003). It is further stated in this report that good management practices, well-defined organizational structures and processes, internal procedures, and standards and regulations specified by legislation have enabled this safe operation of the plants. The conclusion reached was that safety management has always been applied in German nuclear plants.

The surprisingly different views in the discussion about safety management between the nuclear operators and the federal authority might be illuminated by taking a closer look at the basic requirements for safety management systems. A typical list of requirements may be taken from the European Union’s Seveso II Directive (Council Directive 96/82/ EC, 1996). According to this list, the following issues shall be addressed by the safety management system: (1) organization and personnel, (2) identification and evaluation of major hazards, (3) operational control, (4) management of change, (5) planning for emergencies, (6) monitoring performance, and (7) audit and review.

The requirements defined for issues (1) to (5) are clearly specified in nuclear standards and federal ordinances, and the issues relevant for plant operation are included in the operating manuals of the nuclear power plants. The last two issues are essential elements of the management cycle (or Deming Cycle: “Plan, Do, Check, Act”), which is now a core feature of formalized management systems, such as the quality management system specified in international standards (cf. International Organization for Standardization [ISO], 2000).

Issue (6) is concerned with the “adoption and implementation of procedures for the ongoing assessment of compliance with the objectives set by the operator’s major-accident prevention policy and safety management system, and the mechanisms for investigation and taking corrective action in case of noncompliance. The procedures should cover the operator’s system for reporting major accidents of near misses, particularly those involving failure of protective measures, and their investigation and follow-up on the basis of lessons learnt” (Council Directive 96/82/EC, Annex III, 1996).

Issue (7) addresses the “adoption and implementation of procedures for periodic systematic assessment of the major-accident prevention policy and the effectiveness and suitability of the safety management system; the documented review of performance of the policy and safety management system and its updating by senior management” (Council Directive 96/82/EC, Annex III, 1996).

The issues define assessment requirements and improvement cycles on two levels: within the plant as elements of the safety management system and on the level of the utility (or licensee) by asking senior management to review and, if necessary, update both policy and the safety management system. Questions related to the responsibility placed on the utilities through legislation and the assignment of this responsibility to utility management and plant management are discussed later in this chapter.

The following question may arise from the outset: Why is a safety management system now felt to be necessary? When the Seveso II Directive was passed, the European Commission also issued the following statement on the need for a safety management system:

> The introduction of Safety Management Systems has taken account of the development of new managerial and organizational methods in general and, in particular, of the significant changes in industrial practice relating to risk management which have occurred over the past ten years. One of the main objectives pursued by this obligation is to prevent or reduce accidents caused by management

factors, which have proven to be a significant causative factor in over 90% of the accidents in the European Union since 1982 (European Commission, “Chemical accident prevention”).

Thus, it may be deduced that popular management methods applied in the industry have led to the demand for new approaches in safety matters.

In view of recent developments, nuclear operators in Germany have realized that there is a need to improve communication about the quality and “modernity” of their safety management systems. This need includes a willingness to mirror the existing structures in light of the ideals of management theory, such as “integrated,” “process-oriented,” and “indicator-supported” safety management systems, and to ensure the optimization of systems where safety improvements can be achieved (Weihe & Pamme, 2003). The improvements initiated include the industry-wide application of the International Safety Rating System (Chaplin & Hale, 1998; De Norske Veritas, 1990), which has been expanded to include aspects of safety culture (VGB PowerTech, 2002). Furthermore, a project has been started to develop a comprehensive set of indicators for the early detection of declining performance in various safety-relevant processes.

The efforts of the operators are remarkable, but the authorities’ expectations with respect to the implementation of the safety management system described above seem somewhat utopian. One should bear in mind what the experienced safety scientist Andrew Hale has remarked about safety management systems: “Safety management has become such a fashionable term and focus of study that we may be in danger of thinking that it will solve all our problems. We must see it as something to be added on to good engineering and human factors, not as a substitute for them” (Hale, 2001, p. 384).

It may be of interest to look at the experience gained from quality management systems that are designed along similar management principles. Here, too, expectations about the results to be had from the implementation of such systems are often very high. One of the Technical Inspection Association specialists for the certification of such systems commented on such expectations: “A good quality management system tells nothing about the quality of the products produced. Even with a perfect quality management system one can produce junk.”

THE SAFETY MANAGEMENT SYSTEM IN RELATION TO THE GERMAN REGULATORY FRAMEWORK

As mentioned above, countries that have passed goal-oriented or performance-oriented legislation on safety have forced the industry to develop safety management systems. A key feature of this regulation is the explicit decision to place the central responsibility for safety on the management of each company. This important feature has also been included in the IAEA’s nuclear safety regulations on organization (IAEA, 2000).

Germany and several other countries still follow a more traditional approach to legislation. It may be of interest, therefore, to discuss the important question of the assignment of responsibility in the framework of German legislation as compared to its assignment in the goal-oriented legislation discussed above.

One of the licensing conditions specified in Section 7 of the German Atomic Act is that “the applicant for the license shall ensure that the persons responsible for the erection and management of the installation and the supervision of its operation have the requisite qualification.” The persons responsible for the safe operation of the nuclear installation are obviously specified only at the plant level, which is underlined by the fact that the plant manager responsible for safety must, according to federal ordinances, fulfill detailed qualification requirements in order to be accepted by the authorities.

International requirements clearly state that the responsibility for safety shall remain with the licensee:

> The operating organization, as licensee, shall have responsibility for the safe operation of the nuclear power plant. The operating organization shall retain prime responsibility for safety but it may delegate authority to the plant management for the safe operation of the plant. In such cases the operating organization shall provide the necessary resources and support. The management of the plant shall ensure that the plant is operated in a safe manner and in accordance with all legal and regulatory requirements (IAEA, 2000, p. 2).

The German regulation for nuclear safety does not contain such an unequivocal statement about the responsibilities of the operating organization. Because German regulation delegates the responsibility for safety to plant management, it should include and emphasize the provision of the necessary resources as the task of the licensee.

It should be mentioned, however, that the legal framework for radiation protection specified in the Radiation Protection Ordinance does contain very clear requirements concerning the responsibility of the licensee. The ordinance states that persons who require a license to operate a nuclear power plant shall be radiation protection supervisors. It also states that if the body entitled to represent a corporation consists of several members, one of these should be named to the authority to represent the function of the radiation protection supervisor (Strahlenschutzverordnung, 2001). The duties of the radiation protection supervisor are specified in detail and include the following requirements:

1. He shall appoint in writing the appropriate number of radiation protection commissioners for the control and surveillance of the work in question.
2. He shall ensure, by means of appropriate protective measures, and especially by the provision of suitable rooms, protective devices, appliances, and equipment for persons, by appropriate control of operational modes, and by provision of adequate and suitable staff, that the radiation protection principles are observed and that the protective provisions of specified paragraphs of this ordinance are met.

The responsibilities of the radiation protection supervisor—to provide the necessary resources and support in radiation protection matters—are set out in detail because German legislation adopted the international regulations on radiation protection. The lack of similarly clear statements about the assignment of responsibility for safety in nuclear power plants may have been a contributing factor to events observed in the nuclear power plant discussed below.

EXPERIENCE FROM EVENT ANALYSIS

The discussion about the need to clearly indicate within the German legal framework which party is responsible for the safe operation of nuclear power plants has its background in fears that the increasing competition between the utilities in the electricity market and the management methods used in the industry to deal with such challenges may have a detrimental effect on the safety of nuclear power plants. The German Nuclear Safety Commission has recently pointed out that changes in the structural conditions of the nuclear industry and the resulting cost pressures may lead to new challenges with respect to safety-relevant tasks and decisions (Reaktor-Sicherheitskommission, 2002).

Current methods to reduce costs in large companies include programs enabling employees to take early retirement. Such programs are usually agreed upon between the unions and corporate management at the corporate or holding level. They become valid for all companies of the group, and the managers of an individual company belonging to the group then have only a few opportunities to modify the decisions. Early retirement programs often result in loss of expertise, and it may be necessary for the individual company to search for new employees with the appropriate level of competence. Yet, even such intentions may be in conflict with a corporate freeze on hiring or an order to recruit needed employees only from other companies belonging to the group.

Experience shows that large utilities operating nuclear and other power plants apply similar methods to reduce costs. However, when staff-reduction programs are initiated from the headquarters of an operating organization and are applied to nuclear power plants without the necessary care, this strategy may have an unwanted effect on the safety level of the plant through the resultant loss of expertise.

Apart from the direct effects of loss of expertise, such intervention will also have indirect effects. When corporate management decisions to reduce staff or costs do not adequately consider the needs of the plant, the implementation of these decisions may have a serious impact on the safety culture of the plant. Policy statements about the utmost priority of safety will be interpreted afterwards as mere words, with no relevance for daily work. This development may quickly undermine the long-standing efforts of the plant management to enhance safety culture. It is much more difficult to overcome such indirect effects than to compensate for the direct effects of loss of personnel.

Thus, as long as Germany's national legislation does not expressly state their responsibilities for safety, corporate managers in group headquarters are at risk of underestimating how their decisions may affect safety. A more definite regulation has recently come into force in Switzerland (HSK, 2002). This Swiss ordinance on the organization of nuclear power plants contains, in accordance with international requirements, a clear definition of the sole and absolute responsibility of the licensee for nuclear safety, as well as of the duty of the licensee to provide the necessary resources.

The necessary balance between responsibilities and competence does not exist as long as corporate management (or the management of the holding company) has the power to decide about staff reductions in nuclear power plants. The plant manager must have the authority to decide about the number of employees and necessary qualifications if he is to bear the responsibility for plant safety. The obligation to provide the necessary resources would remain with corporate management, as the licensee. Group-wide staff reduction programs without the right of veto for the plant manager are not acceptable.

In earlier publications on the liberalization of the electricity market, the hope has been expressed that commercial considerations might not achieve higher priority than safety aspects (Keil & Glöckle, 2000). In light of the experience presented above, it seems doubtful whether this hope is still justified. Therefore, it may be wise to pay more attention to the statement of a representative of the World Association of Nuclear Operators (WANO): "One of the most visible drivers of change in the electrical industry today is competition. And if nuclear power is to survive, the changes driven by competition must be managed without impacting nuclear safety" (Madden, 1999, p. 1).

This clear statement may be at least partly based on experience gained from the Millstone Nuclear Power Station in the United States. In 1996 *Time* magazine presented a cover story about harassment and intimidation of employees who brought safety concerns to plant management. The problems finally led to a plant shutdown of several years, replacement of the management team, and an expensive program to develop a "safety-conscious work environment" (Carroll & Hatakenaka, 2001). The safety-relevant issues in this case are much more serious than the events that gave rise to the discussion of the issues described above. Nevertheless, the story contains several lessons about the results of short-sighted management decisions, and it should be required reading for corporate managers responsible for the budget of nuclear power plants. The lessons are summarized in the statement of a former president of WANO and former chairman of Ontario Hydro, Robert Franklin (cited by Madden, 1999, p. 5): "If you pursue safety, you get efficiency, if you pursue efficiency, you get an accident."

EXPERIENCE FROM NUCLEAR POWER PLANT INSPECTIONS

In 2002 I was involved in a number of special inspections of nuclear power plants. These inspections were performed in addition to the routine supervisory tasks of the regulatory authority and their technical experts at the Technical Inspection Association in response to an event at one plant. A group of eight inspectors (four from the authority, four from the Technical Inspection Association) visited each of the operating five plants for two days. Neither the exact date nor the four selected focus points of the inspection were announced in advance; the plants had only been informed that unannounced plant visits would be performed. The second phase of the inspection program was the preparation and implementation of the plant-outage phase. In this phase teams of two inspectors visited the plant during different phases of the outage period; the visiting dates were announced ahead of time.

One focus of the inspections and audits was to review selected issues of safety management (preparation and supervision of operational processes; event analysis; planning, preparation and supervision of outages, etc.). National and international standards were used to assess the adequacy of the review findings.

The overall results of the inspections are quite positive. We found well-established safety management of the routine processes relevant to safety. They were well planned, organized, and adequately supervised by the managers responsible for these areas. Differences have been observed in details of the work procedures, the tools used (e.g., how much computer tools are used), and the extent of planning for outages. The long-term planning of personnel and technical resources was also found to be well managed, particularly in plants not belonging to a large utility. The provisions even included plans for the recruitment of specialists due to anticipated problems with the loss of suppliers of nuclear plant components. Hence, it seems one should not generalize about the problems associated with the limited opportunities for some plant managers to have enough influence with respect to personnel decisions made at higher levels of the utility.

It is essential that the responsibility for safety remains with the top management of the operating organization. This requirement implies that safety should be a visible aspect of a company's policy and goals. We found that some of the policy statements and the documented goals of the operating companies did not address safety issues with the necessary emphasis.

When we examined one of the typical features of a safety management system—the management cycle—we found a number of processes in which all elements of the cycle were well established. In some of the plants it seemed there was some lack of management review and control with respect to the performance and completeness of the initiated measures. One reason for this finding might be a lack of suitable indicators to measure safety performance. Well-known indicators like those of WANO are, in fact, applied in all of the plants, but these types of indicators are designed to compare the plants with each other on a more general level. Drawing from experiences gained from peer reviews and from analyses of international developments, some of the plants had already made efforts to develop indicators better adapted to measuring the performance of specific processes.

Meanwhile, one of the utilities has started a project to develop improved indicators to measure the safety performance of the safety-relevant processes of plant operation. Moreover, they will also be useful as early warning indicators to detect decreasing safety performance. There are no ready solutions available on the market which can be adapted to the peculiarities of the various plants. It is quite a challenging task to find adequate indicators to measure safety performance for all relevant processes, which would also be useful in indicating future trends.

Safety management shares much in common with quality management, particularly since the new quality management standards promote the adoption of a process approach (ISO, 2000). The quality management standards also recommend the measurement of quality-relevant performance for any of the various processes. Thus, both the experience gained with quality management systems and some of the methods used in these systems may be transferred to the development of safety management systems. However, one of the lessons learned in this field should be recognized: quality management is only effective when the performance criteria are actually specified and when the necessary resources for monitoring and continual improvement are provided.

SUMMARY

This chapter presents the recent discussions on the implementation of safety management systems in nuclear power plants in Germany. One of its objectives has been to limit the immense expectations of some authorities about the ability of such safety management systems to prevent with certainty all human and organizational errors in nuclear power plants. Rather, efficient self-regulation through the implementation of a formal safety management system in nuclear plants requires a clear assignment of responsibility for safety to the very top of the operating organization, the licensee. This assignment of responsibility should be prescribed by law; in Germany, at least, this prescription does not seem to be clear enough.

The request to implement a more systematic approach to safety management, namely, the safety management system, is the consequence of a few events in nuclear plants in Germany. Special inspections of nuclear power plants showed that although there was efficient safety management of routine processes relevant to safety, there were also opportunities for improvement toward a more systematic safety management system. Some German utilities have already started projects to develop and implement an “indicator-based safety management system” based on a process-oriented approach. However, improvements with respect to safety management should not only focus on plant-internal processes. Instead, it is necessary to emphasize the role of the top management of the licensee as a part of the safety management system. Safety should be a key component in the policy statements and the definition of goals at this very top level of the operating organization. The advantages of a safety management system may only be noticeable with the involvement and active support of the top management for safety and the provision of the necessary resources.

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CHAPTER 12
BEHAVIORAL APPROACHES TO SAFETY MANAGEMENT WITHIN REACTOR PLANTS: A PRELIMINARY STUDY

Sue Cox, Bethan Jones, and Helen Rycraft

This chapter considers the implementation of a behavioral safety program within the nuclear industry, describing how employees within reactor plants view behavioral approaches to safety management. In particular, it addresses the perceived strengths and weaknesses of such approaches to safety and identifies both current and future potential for learning. The objectives of the investigation were (a) to assess employee commitment to behavioral safety and any barriers to its continuing success; (b) to appreciate, in the context of existing theoretical frameworks, how individuals see opportunities for learning through engaging in the initiative; and (c) to develop a broad appreciation of the opportunitiy for expanding the scheme. The preliminary results of the investigation indicate a positive commitment to behavioral safety within the study organization.

INTRODUCTION

Unsafe behaviors are said to both directly and indirectly contribute to 90% of all workplace accidents and incidents (Hollnagel, 1993). Given the importance of behavioral patterns in the accident process, it is not surprising that safety improvements focused on individual behaviors have become popular in the development of safety performance (Cooper et al., 1994; Cox & Cox, 1996). However, the implementation and sustainability of such programs have been variable, and many successful programs that have reportedly improved health and safety performance seemingly have lost momentum (Health and Safety Executive, 2002).

The question of behavior change is intimately tied up with issues of motivation, attitudes, beliefs, learning, and trust. Although, at least in the psychological literature, these constructs and their supporting processes are separable and independent, with respect to the management of safe behavior they appear to become interdependent. Bringing these constructs together in different ways has produced a multitude of interlacing models, theories, and strategies for managing behavioral change. Among the more influential are Fishbein and Ajzen's "theory of reasoned action" (Fishbein & Ajzen, 1975; Ajzen, 1988; Fishbein, 1982), Becker's "health belief model" (1974), and Prochaska and DiClemente's "stages of behavioural change" model (1983). What is clear from critiques of such models is that, in addition to the cognitive processes involved, including issues of learning and reinforcement, there is a powerful social influence at work. Theorists such as Bandura (1977, 1986) have chosen to make these explicit through the development of socio- cognitive theories and theories of social learning. Several researchers (e.g., Connor, 1992) have produced integrated reviews, from which it is possible to develop a list of the main factors (including those not represented in the previous models) that influence safe behaviors (see Table 12.1).

Table 12.1 Factors influencing behavior in relation to health, safety, and risk

Factors influencing behavior	
➢	Human factors, including person-environment fit
➢	Personal characteristics (age, gender, experience)
➢	Established norms of behavior
➢	Attitudes and climate
➢	Attitudes and perceptions of risk
➢	Perception, organization, and environment
➢	Motivation and perception of long-term versus short-term benefits
➢	Motivation
➢	Trust

*Note: Adapted from Pros and cons of social cognition models in heal*th psychology, by M.Connor, 1992 (September), paper presented at Social Cognition Models in Health Psychology, British Psychological Society Health Psychology Section Conference, University of St. Andrews, Scotland.

Although we, the authors, are attracted to socio-cognitive explanations of behavior change, in this chapter we discuss an intervention that also has focused on learning processes closely related to theories of reinforcement and conditioning (Skinner, 1974) and goal-setting (Locke & Latham, 1991). Moreover, there is a growing recognition of the importance of trust within and among the various operational teams for a process to be effective. Yet, although trust has been identified as an important construct in organization studies (Lane & Bachmann, 1998), it has not been fully examined in the field of behavioral safety. This circumstance may be explained from an evolutionary perspective. First, safety, particularly in high-hazard environments, has traditionally been associated with command-control relationships rather than with empowerment; second, much of the existing work on trust is ridden with conflicting prescriptions for its generation and maintenance (Hardy et al., 1998); and, finally, although researchers such as Cynthia Hardy have observed that trust is associated with predictable behavior patterns, there are still issues surrounding the general acceptance of the behavior change process which seem restrictive in relation to the generation of trust.

The current study of a behavioral change initiative was undertaken as part of a larger European research project, LearnSafe (see Wahlström in this volume: Chapter 2), and was focused on participant feedback about a program of "behavioral safety" across nuclear reactor plants within the study organization. It attempts to develop the understanding of the potential of a custom-made behavior change initiative within the overall safety management system.

Purposes and objectives

The focus of the investigation is on personal inputs into and experiences of the behavioral safety process over a four-year period, rather than on organizational safety performance per se. The chapter includes a brief description of the processes and methods utilized within the organization, in order to give some background to the study. The main focus of the work to date has been an interpretation of participant perceptions as to the value of this "innovative" approach to the process of individual learning and behavior change and the impact of the program on the dynamics of trust and control within the participating plants.

The objectives are (a) to assess employee commitment to behavioral safety and any barriers to its continuing success; (b) to appreciate, in the context of existing theoretical frameworks, how individuals see opportunities for learning through engaging in the initiative; and (c) to develop a broad appreciation of the opportunities for expanding the scheme. Further investigations are planned within the overall aims of the LearnSafe project.

Behavioral safety program: A brief synopsis

The behavioral safety program under consideration in this chapter was introduced as part of a broader accident prevention program and was initially focused on "conventional" safety rather than nuclear safety. The program has recently been extended to include other areas, including environmental management, leadership, and nuclear safety.

The development of the program began in 1997 and originated from two proprietary approaches. Two separate sites within the organization had independently approached external consultants to implement proprietary programs within work teams. One program had both trade union and employee support; the supervisors at the plant, however, reported feeling excluded from this program. This particular program was based upon behavioral reinforcement and introduced by Behavioural Science Technology Inc., after a period of on-site training (Krause et al., 1999). The other program was focused on cultural change and had more involvement from management teams. It was reported that the increased managerial influence had left employees feeling as though the program was forced upon them. A cross-sectional team was thus established within the organization, and a custom-made program (incorporating many of the key issues in Table 12.1) was developed and rolled out within the wider organization (see Figure 12.1)

Two of the authors were involved in the development of the program and were closely involved in the initial launch. The process was implemented within all business groups of the organization, and a target of approximately two years was set for implementation. A template model of behavioral safety was presented to each site within the organization. Individual sites were then required to personalize the process by adding pictures of the site and examples of incidents or accidents that had actually occurred on site. This strategy gave individuals a sense of ownership of the approach, as it incorporated examples to which they could actually relate. A series of training sessions and workshops were held for employees at various levels within the organization (see Figure 12.2), with the aim of such sessions being (a) to ensure that employees were informed about the development of the process, (b) to explain how the process would be implemented, and (c) to highlight the desired outcomes of utilizing behavioral safety.

The foundation of the approach was based on the goal to develop a partnership of trust between managers, unions, and employees. The program has now been in operation for several years and is recognized throughout the company as an effective element of the safety management system.

METHODS

Personnel from two representative nuclear power plants and other key stakeholders in the behavioral safety process participated in the study. Data collection methods included semi-structured interviews, plant observations, and questionnaires. Participants included a Behavioral Safety Process (BSP) champion (n=1), BSP coordinators (n=2), the BSP data manager (n=1), BSP site coordinators (n=2), BSP observers (still recruiting), and employees who have been observed as part of the program (still recruiting).

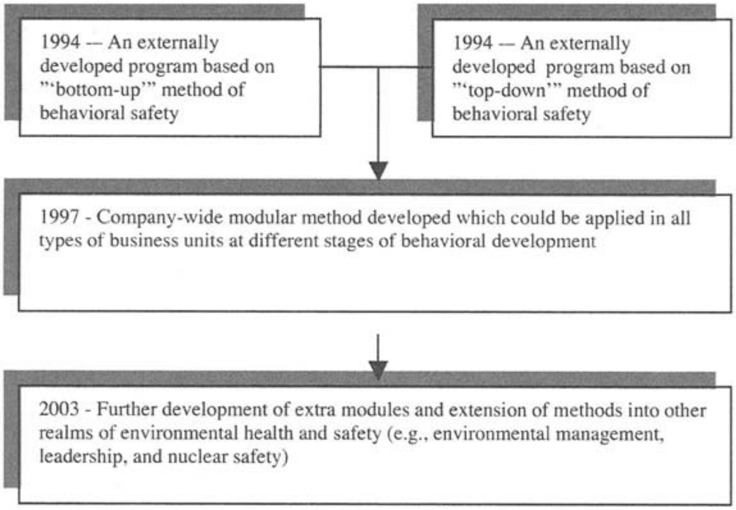

Figure 12.1 An outline of the development of a custom-made behavioral safety program.

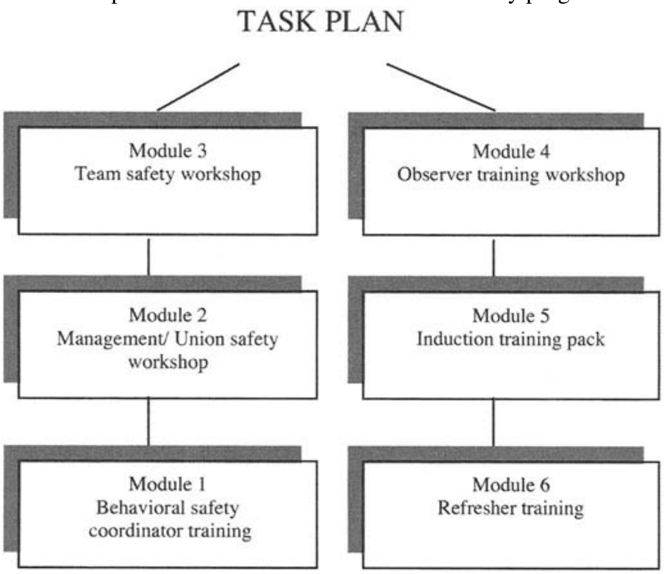

Figure 12.2 An outline of behavioral safety implementation within the organization.

Semi-structured interviews

The principal investigators interviewed a number of key personnel within the company about their inputs into and experiences of behavioral safety. Participants included employees from various levels within the process. Each of the participants occupied a key role and was included in the study through an opportunity sampling process.

Interviews lasted approximately one hour and were either face to face or over the telephone. A semi-structured interview schedule was used, and the interviews were transcribed. The transcripts were analyzed using content analysis. Content analysis is a data reduction method by which communication content is transformed, through the objective and systematic application of categorization rules, into data that can be summarized and compared. The benefit of content analysis is that it allows researchers to generate frequencies from qualitative data, yet still maintain the richness of the data.

Site visits

The researchers also visited two representative nuclear power plants in order to gather data from employees. Participants involved during this stage of the research were either actively involved in the behavioral safety process as observers or involved as employees who had their work observed in the process. During each of the visits to the nuclear plants the researchers conducted a site "walk-about," informally talking to employees and asking them to discuss what they believed to be the strengths and pitfalls of the behavioral safety process. These data were collated in a "site narrative" and subsequently analyzed for core constructs and opinions. Site managers were given feedback on site-wide issues in relation to the program.

Questionnaire study

A questionnaire, designed to assess employee attitudes to behavioral safety, was tested for face validity with an expert panel and was subsequently amended and cleared for distribution at the plants. The BSP site coordinators (at each of the nuclear plants) agreed to distribute questionnaires during site safety meetings. Participants returned completed questionnaires directly to the researchers.

RESULTS

Data were analyzed using both qualitative and quantitative methods.

Qualitative analysis

Transcripts of the interviews were closely analyzed by each of the researchers and subjected to a preliminary content analysis (see Dane, 1990; Holsti, 1969) involving two raters. The key concepts, presented in Table 12.2, are based upon the most commonly occurring words in relation to the study objectives.

Table 12.2 Key concepts based on the most commonly occurring responses to core questions

Perceived strengths	Perceived pitfalls	Learning potential/outcomes
Increases safety awareness	Unreal expectations	Opportunities for communication/ knowledge-sharing
Promotes communication	Requires foundation of trust	Source of valuable knowledge for local learning
Partnership between managers, unions, and employees	Could be used negatively as a "weapon"	Builds awareness of safety and site values
Increases interaction between employees and supervisors	More feedback needed Reluctance to be observed	Enables and reinforces learning from mistaken actions
Linked to events on site	Certain teams/groups deliberately undermine approach	Direct link between behavior and consequences
Encourages sharing of knowledge and learning from mistakes	Difficulties of maintaining enthusiasm	
Highlights a direct link between behavior and consequences	Management of consequences	

Perceived strengths	Perceived pitfalls	Learning potential/outcomes
Focus on all levels Development of employee skills Builds safety into culture Ownership of solutions Raises profile of safety Increases safety on site Everyone is responsible for safety Transferable	Slows other work/procedures	Employee behavior has an impact on others. Problem identification and employee-driven solutions Challenging Reinforcing nature of approach with tangible benefits Praise given for safe behavior

During the course of the semi-structured interviews, interviewees identified a number of specific eamples of safe behaviors, which they had learned through the behavioral safety process. They also reported a number of employee-driven solutions to safety problems and specific examples of learning (see Table 12.3).

Table 12.3 Employee-driven solutions to safety problems and specific examples of learning

Learning with behavioral safety
"On one occasion I was observing an employee performing a task. Whilst carrying out this task I observed acid splashing up onto the employee's face. The splashing of the acid actually caused the mask to crack. After the incident, during an informal conversation, the employee confessed that he may not have worn the mask, but for the fact that he knew that he was being observed and, as a result, he ensured that he was wearing full Personal Protective Equipment."
"Thirty percent of all accidents on a particular site involved cuts and abrasions to hands or fingers. A safety group discovered the root cause was that people were carrying out tasks without wearing gloves, usually because the correct gloves were unavailable or the task only took a few minutes, and therefore the workers had been reluctant to go and find any. The team agreed that the way to address this problem would be to provide people with Personal Protective Equipment bum/waist bags; the bags would be worn at all times and could contain safety equipment such as gloves, glasses, etc. The bags were issued, and the percentage of unsafe acts involving hands is reducing."
"During a conference attended by around 300 employees, the speaker (the chief executive) was walking close to the edge of the stage when one employee on the front row pointed out that this was in fact a potential unsafe act, with the consequences being that the speaker could possibly fall from the edge of the stage. The speaker thanked the employee for pointing him to the danger and duly remained behind the podium for the rest of the lecture, thus avoiding a potentially dangerous fall from the stage."

Quantitative analysis

Completed questionnaires were returned by post and then subjected to analysis by the researchers. Data gathered from the questionnaires will be subject to analysis of variance and T-tests using SPSS to uncover key concepts (this work is currently underway). Preliminary findings suggest there is a positive commitment toward the behavioral safety process within the study organization.

DISCUSSION

During the course of the interviews, participants highlighted the importance of the behavioral safety process to the nuclear industry. Interviewees reported that behavioral safety was of great value to the nuclear industry as it assisted cultural realignment toward a culture that was more focused on safety. The approach was perceived as proactive at all levels within the study organization. Participants also believed that the behavioral safety process was an effective motivational tool, which assisted change in both behavior and attitude. The manner in which the process was developed (see Figure 12.1) was also perceived as effective.

Many of the key issues highlighted by participants focused on the link between attitude change and behavioral safety. Attitudes and their link with behavior are acknowledged by many as playing a central role in workplace health and safety management. With their theory of reasoned action, Fishbein and Ajzen (1975) have proposed a complex process in the route from attitudes to behavior. According to this theory, behavior can be predicted if observers know (a) the person's attitude to the particular behavior, (b) the person's intention to perform the behavior, (c) what the person believes are the consequences of performing that behavior, and (d) the social norms which govern that behavior. However, the behavioral process (see Table 12.2) can facilitate satisfying each of these conditions, thereby enabling predictions of behavior. Findings from informal discussions with employees at each of the sites also indicate that, in many instances, safe behaviors follow from social pressure rather than from predisposing attitudes or intentions.

It is generally accepted that at all levels learning plays an important role in safety performance within high-reliability organizations such as nuclear power plants (Carroll, 1998). Argyris and Schön (1978) have also stressed the importance of learning-in-action in periods of major change, in addition to the complexities of both plant and operation. Findings from the current study indicate that utilizing a behavioral safety approach results in a strong potential for learning (see Table 12.2). Behavioral safety programs appear to be successful in increasing opportunities for communication and knowledge-sharing between employees, as well as in facilitating and reinforcing the need to learn from mistaken actions. Individuals reported an increased awareness of safety and site values and an ability to perceive a direct link between performing specific behaviors and their safety consequences. Data gathered from both the semi-structured interviews and site visits uncovered a number of specific examples showing how behavioral safety has resulted in behaviors actually being learned at the individual level.

It is also possible that organizations undertaking a behavioral safety program will promote organizational learning because such initiatives provide the opportunity for individuals to communicate and interact, thus enabling the sharing of knowledge and experiences. However, the link between individual and organizational learning occupies a critical position within many theories of organizational learning. Many theorists believe that organizational learning begins with the individual. Simon (1991) has rejected the notion that organizations themselves learn, claiming that "all learning takes place inside individual human heads" (p. 125). He thus proposed that organizations learn through the learning of their members. Dixon (1999) believes that each member of an organization has the capability to learn and that an organization learns through the capability of its members. Therefore, organizational learning is not simply the sum of all that its members know; rather, it is a collective use of this capability of learning (Dixon, 1999). Behavioral safety could be viewed as a vehicle for mobilizing such capability.

Trust was felt to be an important element in the design of the behavioral safety process. Identification-Based Trust (IBT) is described by Maguire et al. (2001) as an ongoing confidence in the predictability and goodwill of the trustee, grounded in trustee-trustor identification; IBT is underpinned by normative control, which is covert and unobtrusive. IBT is generated by shaping and molding identities in ways that increase identification between trustor and trustee (Maguire et al., 2001). The custom-made behavioral safety program under investigation within the current study is built upon a foundation of trust between key stakeholders; that is, it is a partnership between managers, employees, and unions. Data analysis uncovered a number of key concepts (see Table 12.2) that were related to the issue of trust. Interviewees reported that behavioral safety will fail in its objectives if trust between key stakeholders is not evident, if it is used as a managerial tool to spy on employees, if it is used as a weapon against employees, or, finally, if there is a lack of consistency with the organization's "just culture" (Reason, 1998).

Participants identified what they perceived to be the strengths of the behavioral safety approach (see Table 12.2). During both the semi-structured interviews and site visits individuals reported that the implementation of a behavioral safety approach had increased safety awareness throughout their reactor site and at the same time promoted communication and interaction between employees and supervisors. Participants believed that the process of behavioral safety was particularly advantageous in that it was able to highlight a direct link between behavior and the consequences of such behavior, as well as encourage the sharing of knowledge and learning from mistakes. Employees involved in the current investigation suggested that the most important strengths of a behavioral safety approach are that the process is built upon a partnership of trust between managers, unions, and employees and that it encourages individuals at all levels within the organization to become actively involved in the achievement of a safe working environment.

Finally, participants involved in the current investigation also highlighted a number of perceived pitfalls (see Table 12.2). Individuals reported that there were often unreal expectations surrounding the use of the behavioral safety process. They also noted that the approach would not succeed without a solid foundation of trust between the main stakeholders; alluding to this issue of trust, participants also indicated that the approach would fail if it were used negatively as a "weapon." Individuals felt that more information about the observations needed to be fed back to them and that more attention needed to be focused on actually managing the consequences of behavioral safety observations. It was also reported that many individuals showed an initial reluctance to being observed and that certain teams or groups deliberately undermined the behavioral safety approach. As time has passed behavioral safety coordinators have reported that it often has been difficult to maintain individual enthusiasm toward the approach. This issue of sustainability has been highlighted in a number of other initiatives (Health and Safety Executive, 2002).

SUMMARY

This research has examined the extent to which behavioral safety, a program based on behavioral reinforcement and change, was perceived to have improved individual learning capability and facilitated organizational safety improvements within the study organization. The current study, undertaken as part of the LearnSafe project, also explored the impact of the behavioral approach on two representative reactor sites. The first phase of the study comprised interviews of key stakeholders in the process, including coordinators, observers, and designers. Data collection is ongoing; preliminary results have been considered in relation to a variety of interpretative and theoretical frameworks.

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PART FOUR

Nuclear Operations and the Public Response

INTRODUCTION

The last two chapters of this volume form Part Four and deal with political and environmental issues—the public reaction toward nuclear power generation. Chapter 13 by Ato, Kitada, and Hayashi shows how Hayashi's Quantification Method was used to analyze data regarding attitudes toward nuclear power. The data base is formed by five regionally representative survey samples in Japan between 1993 and 2000. The objective of the survey studies was attitudes toward nuclear power generation, images and understanding of nuclear power, and a variety of public perceptions related to nuclear risk and power. Of particular interest may be their finding on the rise of anxieties after reported nuclear accidents. On the whole, the chapter complements through its general overview and advanced analytic methodology the preceding chapters which focused more on the plant level.

The final Chapter 14 by Hashiba widens the perspective once more by addressing even a broader environmental issue—public attitudes toward energy saving, nuclear power, and renewable energy and the role of CO_2 emission in relation to global warming. Again, a random regional Japanese sample was used, and sophisticated structural equation modeling techniques were implemented in the data analysis. Most important of the complex picture resulting from the comprehensive survey seems the finding that accident fears in the population overshadow the valiant attempts of industry and government to convince the public of the beneficial environmental effects of nuclear power production.

CHAPTER 13
NUCLEAR POWER GENERATION IN JAPAN: PUBLIC AWARENESS AND ATTITUDINAL STRUCTURES

Kazunori Ato, Atsuko Kitada, and Chikio Hayashi

With the use of data from continuous awareness survey data, an analysis based on Hayashi's Quantification Method Type III (correspondence analysis) was carried out on the general relation of attitudes toward nuclear power generation, awareness of energy and environmental problems, views about the scientific community, other general aspects of awareness, and attitudinal structures. The analysis revealed that attitudes toward nuclear power generation do not exist in isolation, but instead develop their specific structure in connection with environmental problems, views about the scientific community, political affiliation, an inclination to give neutral responses, and other aspects, including an interest in supernatural phenomena, ghosts, and superstition. A comparison of the results for 1993 and 1998 showed that these connections had not significantly changed. Attitudes toward the use of nuclear power generation were not significantly affected by accidents. Public support for the use of nuclear power generation, though not explicit, was identified.

INTRODUCTION

With the aim of measuring public opinion on nuclear power generation, the Institute of Nuclear Safety System, Inc., conducts awareness surveys periodically as well as after major nuclear-related accidents. On the basis of the data from these surveys, changes in public attitude toward nuclear power generation are determined. In addition, the attitudinal structure of the overall relation between attitudes toward nuclear power generation, on the one hand, and various other attitudes and aspects of awareness, on the other, is determined in order to examine whether the attitudinal structure has changed over time.

DATA

Six awareness surveys on nuclear power generation were conducted between 1993 and 2000 (Table 13.1). In 1996, 1997, and 1999 an awareness survey was conducted one year after the occurrence of a nuclear-related accident to examine the effects of the respective accident. In 2000 an awareness survey was conducted to determine the change in the effects of an accident two months after its occurrence (for overviews of individual accidents, see Kitada, Ato, & Matsuda, 2001). The respondents, males and females between the ages of 18 and 79 living in the Kansai area, were selected by the stratified two-stage probability sampling method. The survey was conducted by distributing questionnaires that were later collected. The number of samples and response rate are shown in Table 13.1. The questionnaire asked about attitudes toward nuclear power generation, images of nuclear power, one's understanding of nuclear power, the responses by the electric power utility, energy problems, environmental problems, the respondents' sense of anxiety and risk, views of the scientific community, social consciousness, political attitudes, national character, the respondents' degree of exposure to information, and respondent attributes.

Table 13.1 Outline of the awareness surveys

	Survey conducted in	Number of samples	Response rate
First regular survey	January 1993	1,500	75.9%
Two months after the Monju accident	February 1996	750	74.9%
Two months after the accident in an asphalt solidification facility	May 1997	750	71.0%
Second regular survey	July 1998	1,500	70.3%
Two months after the JCO accident	December 1999	750	70.9%
One year after the JCO accident	October 2000	1,500	70.4%

RESULTS

Image of nuclear power: Responses to open-ended questions

We asked the respondents to freely describe what they felt was most dangerous to them, and organized these descriptions into eight categories (Table 13.2). Transportation disasters and natural disasters accounted for 60%. The 10% increase in 1998 with respect to natural disasters was most likely due to the occurrence of the Great Hanshin Earthquake. The perception of dangers arising from nuclear power generation showed little change, accounting for only 2.8% even two months after the occurrence of the JCO accident in 1999. This result indicates that the respondents usually are not highly aware of dangers arising from nuclear power generation.

We also asked the respondents to freely describe what they associated with the term "nuclear power" and broke these descriptions down into eight categories (Table 13.3). Predominant among these responses were negative images such as "wars, atomic bombs, and nuclear weapons," "accidents and explosions," "radioactivity, environmental pollution, and waste," and "dangers and anxiety." More than half of the public polled described negative images: nuclear power does not enjoy a good image. However, even two months after the JCO accident the quality of the responses did not change significantly. It seems that the negative image of nuclear power was already in place and was not affected by an accident of the scale of that at JCO Company, Ltd.

Table 13.2 Responses to open-ended question about what respondents regard as most dangerous (in %)

	1993	1998	1999	2000
Transportation disaster	42.3	31.5	29.3	24.3
Natural disaster	17.8	27.5	31.8	36.1
Environmental disruption and pollution	5.3	4.8	4.1	2.7
Fires	5.2	3.4	3.9	2.6
Human relations	1.0	3.4	5.3	6.1
Wars	1.6	1.5	1.5	1.0
Nuclear power	1.2	1.2	2.8	1.6

	1993	1998	1999	2000
Diseases and other	2.2	4.3	4.7	5.0
No response	23.5	22.3	16.5	20.6
Total	100.0	100.0	100.0	100.0

Table 13.3 Responses to open-ended question about associations with "nuclear power" (selection of all that apply allowed; in %)

	1993	1998	1999	2000
Energy and fuel	7.1	4.6	6.0	5.0
Electricity, electric power, and power generation	38.5	44.1	41.2	37.0
Wars, atomic bombs, and nuclear weapons	28.6	25.6	24.8	20.5
Accidents and explosions	17.2	15.4	19.2	19.0
Radioactivity, environmental pollution, and waste	18.3	15.0	18.6	17.2
Dangers and anxiety	5.7	8.5	9.2	8.0
Tokai Village			1.1	0.7
Others	13.9	12.0	11.1	8.2

Anxiety about accidents in nuclear facilities

Respondents were asked about the degree to which they were anxious about accidents in nuclear facilities. Figure 13.1 shows the change in answers from 1993 onward. Fifty to sixty percent of the public answered "very anxious" or "considerably anxious," indicating a high level of anxiety about accidents in nuclear facilities. Yet, as discussed in the section on the significant difference between plants, the respondents usually did not consider the dangers of nuclear power when asked to freely name what they considered most dangerous. It seems that a sense of anxiety emerges when respondents are asked about an accident and have it brought to their attention. The percentage of those who felt "very anxious" rose significantly after the Monju accident. It declined slightly in 1998 and again rose significantly two months after the JCO accident, then returned to the 1998 level after one year. This result shows that, although an actual accident causes anxiety about accidents to increase, such anxiety is transient. The asterisks in Figure 13.1 indicate a statistically significant difference. To test the difference in the response rate, an empirical value of about 2, which is the ratio of the variance of errors in the stratified two-stage probability sampling to that of errors in the unrestricted random sampling, was used. A difference was judged significant at the 5% level.

Opinions on the use of nuclear power generation

Figure 13.2. shows how opinions on the use of nuclear power generation have changed over time. After the Monju accident and the accident in an asphalt solidification facility, the percentage of those who held favorable or passive opinions of nuclear power generation, describing it as "good to use" or "inevitable," decreased slightly. In 1998, however, the percentage of respondents who felt that nuclear power generation was "inevitable" increased significantly, whereas the percentage of those who thought nuclear power generation "should not be used" decreased significantly. Hence, the overall picture was a positive one.

Two months after the JCO accident the percentage of those who thought that nuclear power generation was "good to use" decreased slightly. However, none of the alternatives showed a significant difference

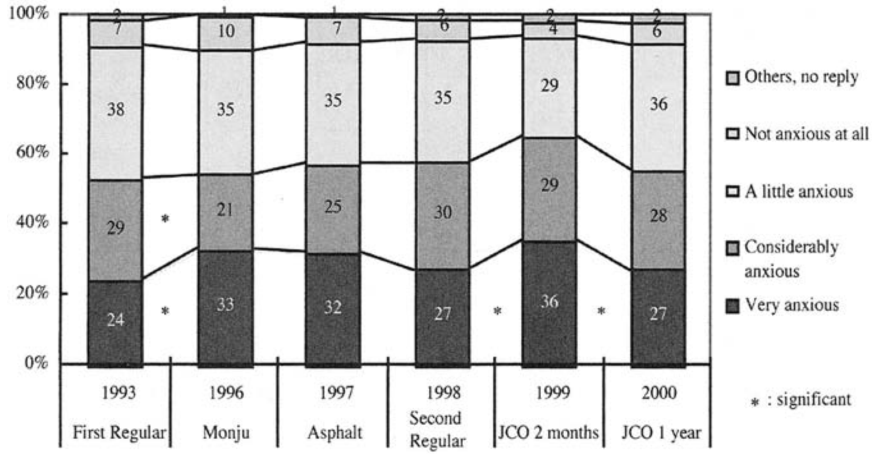

Figure 13.1 Anxiety about nuclear facility accidents.

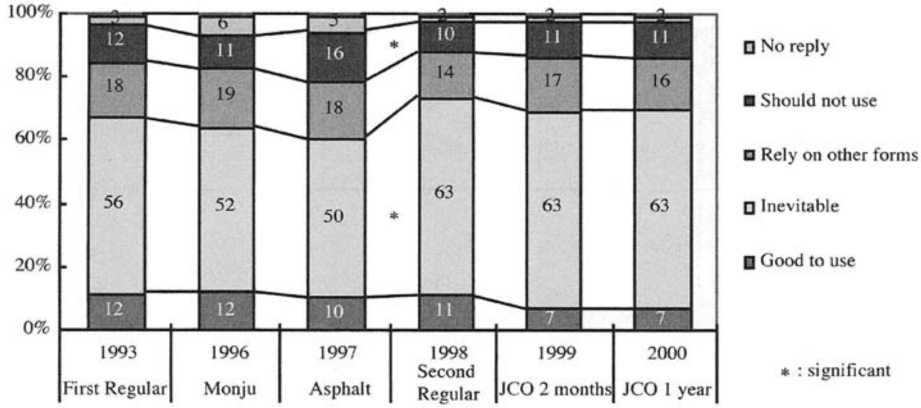

Figure 13.2 Opinions on the use of nuclear power generation.

from the trend in 1998, and there was no change one year later. The survey completed two months after the JCO accident showed not only an increase in anxiety about nuclear facility accidents, but also negative responses about nuclear power. These negative responses were not necessarily connected directly with a desire to see an end to the use of nuclear power generation. Opinions on the use of nuclear power generation can be said to be less sensitive to the effects of an accident than is the anxiety generated by such accidents. Those who gave passive approval, that is, who thought the use of nuclear power generation “inevitable,” accounted for 63%. Taken together with those who thought nuclear power generation “good to use,” the percentage of respondents who approved of the use of nuclear power generation amounted to 70%. This overall situation has not changed significantly.

ATTITUDINAL STRUCTURE IN RELATION TO NUCLEAR POWER GENERATION

Method of analysis

In order to analyze attitudinal structures we used the data acquired in the periodic surveys of 1993 and 1998, as these sets of data are thought to be little affected by the accidents. First, each respondent's overall attitude to nuclear power generation was classified. The procedure for classification was as follows. After combining the data obtained in 1993 and 1998, Hayashi's Quantification Method Type III (correspondence analysis) was applied to the answers for the eight questions directly related to the attitude toward nuclear power generation as variables. Because it was confirmed that the first axis category score provided the scale for the attitude toward nuclear power generation, the first axis sample score was defined as the overall index for the attitude of a respondent toward nuclear power generation. Through use of the sample score distribution, the attitude of a respondent toward nuclear power generation was categorized according to five levels: "very unfavorable," "unfavorable," "neutral," "favorable," and "very favorable."

This study is primarily concerned with the attitudinal structure related to nuclear power generation that is the overall relation between attitudes toward nuclear power generation, (determined through the classification described above) and the answers to other questions. These other questions concerned the image of nuclear power; the respondents' understanding of nuclear power; energy problems; environmental problems; anxiety; the respondents' sense of risk; their views of the scientific community; social consciousness and political attitudes; the inclination to give neutral answers; the respondents' confidence in other people; leadership characteristics; and interest in the supernatural, ghosts, and superstition. The answers to these questions were organized into the categories shown in Table 13.4. Moreover, with all the categories in the table taken as variables, the data obtained in 1993 and 1998 were analyzed separately using Hayashi's Quantification Method Type III in order to compare the results for two years.

Table 13.4 Items and categories used to analyze attitudinal structure

Item	No.	Category
Number of important items	1	Small
	2	Rather small
	3	Medium
	4	Large
Number of useful items	5	Small
	6	Medium
	7	Large
Interest in accidents	8	Slight
	9	Moderate
	10	Strong
Energy problems	11	Very important
	12	Important
	13	Not important
Knowledge of nuclear power	14	Have some knowledge
	15	Have little knowledge

Item	No.	Category
	16	Cannot say whether knowledgeable or not
Chernobyl accident	17	Remember it well
	18	Remember it a little
	19	Do not remember it
Degree to which a respondent worries in general	20	Small
21	Moderate	
	22	Great
Japan's power-generating capability	23	Sufficient
24	Rather sufficient	
	25	Neither more nor less
	26	Rather insufficient
	27	Insufficient
What a respondent wants to know about nuclear power	28	Functioning
29	Local promotion	
	30	Nothing in particular
	31	Necessity
	32	Cost-efficiency
	33	Safety
	34	Past accidents
	35	Disaster prevention organization
	36	Effects of radioactivity
	37	Waste disposal
	38	Difference from an atomic bomb
Japanese approach to viewing	39	Weak
leadership	40	Moderate
	41	Strong
Most dangerous thing	42	Transportation accidents
	43	Natural disaster
	44	Environmental destruction
	45	Fires
	46	Damage and injury due to crime
	47	Wars
	48	Radioactivity from nuclear power generation
	49	Diseases and other
Confidence in other people	50	Weak
	51	Moderate
	52	Strong
Interest in the environment	59	Deeply interested
	60	Quite interested

Item	No.	Category
	61	Interested
	62	Little interest
Attitude toward nuclear power generation	63	Very unfavorable
64	Unfavorable	
	65	Neutral
	66	Favorable
	67	Very favorable
Political party supported	68	Liberal Democratic
	69	Democratic and Sakigake
	70	Komei
	71	Social Democratic
	72	Communist
	73	No party supported
View of the scientific community	53	Very negative
54	Rather negative	
	56	Neutral
	57	Rather positive
	58	Very positive
Inclination to give neutral answers	74	Weak
75	Moderate	
	76	Strong
Interest in ghosts	77	Little interest
	78	Moderately interested
	79	Greatly interested
Degree to which a respondent is superstitious	80	Not superstitious
81	Fairly superstitious	
	82	Very superstitious
Associations with nuclear power	83	Energy
84	Electricity	
	85	Nuclear wars
	86	Accidents
	87	Radioactivity
	88	Danger and anxiety
	89	Other

Note: The numbers correspond to those in Figures 13.3, 13.4, and 13.5.

Indifferent stratum expressed on the first axis

Figure 13.3 shows the plot of the first and the second axis categories for 1998 (details are shown for major categories, with the other options denoted by the numbers used in Table 13.4). On the plus side of the first

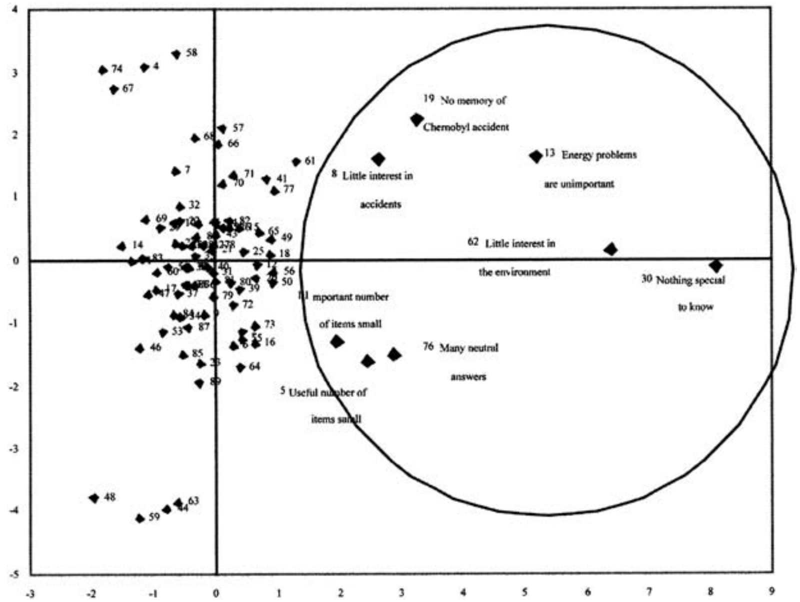

Figure 13.3 Attitudinal structure for 1998, first axis (horizontal) x second axis (vertical).

axis, the items characteristic of indifference, such as "no desire special to know about nuclear power generation," "little interest in the environment," and "energy problems are not important," were extracted. The plot for 1993 shows the same characteristics. In other words, among all the respondents, the group showing indifference and selecting these items had the most notably different patterns of response.

In order to examine the characteristics of the group showing indifference, those who had larger first-axis respondent scores were classified as belonging to the group showing indifference (8% of all respondents); they were compared with both the overall response rate and the rate in the group with a neutral attitude toward nuclear power generation. The results of the comparison are given in Table 13.5. The group showing indifference consisted mainly of females between 18 and 29 years of age who had an elementary and junior high school education. The people in this group had less anxiety about nuclear facility accidents, were extremely indifferent to the activities of citizen groups, and gave less support to local referendums. Moreover, few of them strongly believed that the state and electric power utilities do not tell the truth and considered themselves capable of changing their own lifestyles in order to reduce the amount of electricity they use. In addition, it was characteristic of the group showing indifference not to read newspapers or watch TV; they therefore had fewer opportunities to become informed.

Table 13.5 Characteristics of the group showing indifference (in %)

Item	**Percentage of total respondents**	**Percentage of group showing indifference**	**Percentage of neutral group**
Sex: Female	55	66	62
School education: Elementary and junior high school graduates	18	33	18
Age: 18 to 29	20	27	20

Item	Percentage of total respondents	Percentage of group showing indifference	Percentage of neutral group
Accidents in nuclear facilities: Very anxious+ Considerably anxious	47	26	52
Activities of citizen groups: Very interested+Rather interested	52	11	51
Support for local referendums	82	62	88
Think "strongly" that the state and electric utilities do not tell the truth	27	2	23
Can change lifestyle to reduce use of electricity	66	44	68
Exposure to information: Little+Limited	47	85	50

Attitude toward nuclear power generation as expressed by the second and third axes

The constellation of second and third axis categories for 1993 is shown in Figure 13.4. The constellation for 1998 is shown in Figure 13.5. The constellations in both figures are similar, with "very unfavorable," "unfavorable," "neutral," "favorable," and "very favorable" attitudes toward nuclear power generation coming one after another in that order. To draw a comparison between the connection of categories in 1993 and 1998, the five different attitudes toward nuclear power generation were placed at the center of five different circles. The 1993 categories contained in the areas formed by the five circles were then compared with the 1998 categories contained in the same way. More than 80% of the answers were included in the same domains or in neighboring common domains, thus demonstrating no great change in the positional relationship between attitudes toward nuclear power generation and opinion items (categories). We thus concluded that the structure of attitudes toward nuclear power generation is stable.

Characteristics of the attitude types

The items that exhibited stable connections from 1993 through 1998 were regarded as indicative of the characteristics of an individual attitude. The following summarizes the individual attitudes:

1. Respondents whose attitude was "very favorable" had positive views of the scientific community, gave fewer neutral answers, were less interested in ghosts and supernatural phenomena, thought of themselves as having some knowledge of nuclear power (subjectively), and were not superstitious.
2. Those whose attitude was "very unfavorable" considered nuclear power, radioactivity, and environmental destruction to be sources of the greatest danger, were greatly interested in the environment, had negative views of the scientific community, thought of themselves as having some knowledge of nuclear power, and were not superstitious.
3. Those whose attitude was "neutral" were given to worrying and were very interested in accidents, were superstitious and highly interested in ghosts and supernatural phenomena, thought of themselves as

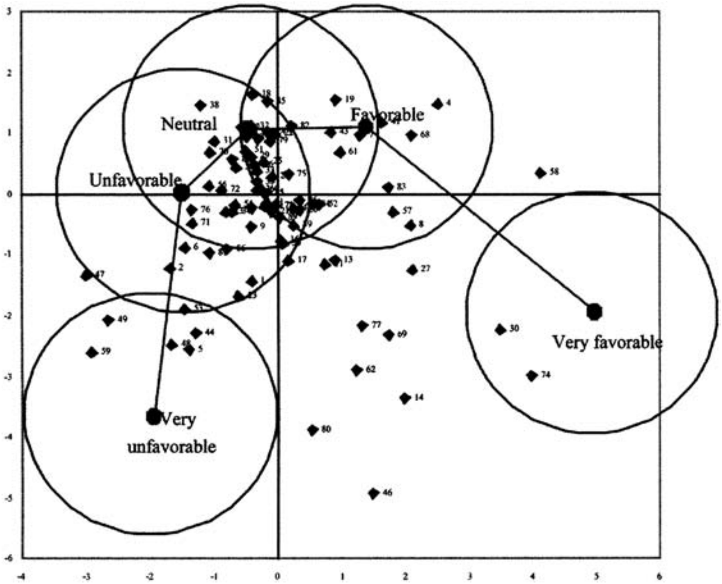

Figure 13.4 Attitudinal structure for 1993, second axis (horizontal) x third axis (vertical).

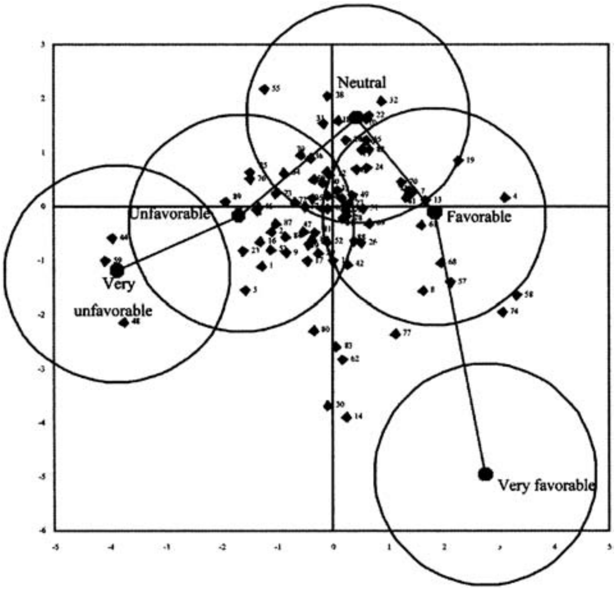

Figure 13.5 Attitudinal structure for 1998, second axis (horizontal) x third axis (vertical).

having little knowledge of nuclear power (subjectively), and remembered the Chernobyl accident a little.

4. Respondents whose attitude was “favorable” had somewhat positive views of the scientific community, were less interested in the environment, liked Japanese-style leadership, and evaluated the importance of aircraft and similar technology highly.
5. Those whose attitude was “unfavorable” associated nuclear power with accidents, faults, environmental pollution, and radioactivity and thought that Japan’s power-generating capability was sufficient.

It should be noted that the strong attitudinal characteristics of respondents who had “very favorable” or “very unfavorable” attitudes to nuclear power generation were common to two types of people: those who thought of themselves as having some knowledge of nuclear power and those who were not superstitious. These people can be regarded as having common traits.

SUMMARY

The image the public harbors toward nuclear power is not good, and the sense of anxiety about nuclear facility accidents is high. A sense of anxiety temporarily increases two months after an accident in a nuclear facility, but then diminishes rather quickly. In comparison, attitudes toward the use of nuclear power generation were not affected by accidents as much. The public supports the use of nuclear power generation, though not in an explicitly positive way.

A comparison of the attitudinal structures with respect to nuclear power generation, using survey data from 1993 and 1998, revealed that the group showing indifference exhibited the most notable characteristics in response patterns and had less exposure to information. We were also able to confirm that the relation observed in 1993 between attitudes toward nuclear power generation and other types of awareness is qualitatively not very different from the identical relation observed in 1998; the relation, therefore, is stable. Thus, although the problem of global warming has come to the fore and increased interest in the environment, these changes are not connected with attitudes toward nuclear power generation, which has the advantage of not emitting CO_2. We also found that attitudes toward nuclear power generation were not independent of other factors; rather, they were connected with various types of awareness to form attitudinal structures. For the time being, no change has been observed in these connections, that is, in the way of thinking about nuclear power generation in relation to other concerns and factors. If in the future change does occur in the logic of thinking behind attitudes toward nuclear power generation, we expect that such change can be identified by carrying out a comparison of the series of attitudinal structures determined thus far.

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CHAPTER 14
PUBLIC RESPONSE IN JAPAN TO CO_2 EMISSIONS: ASSESSING ELECTRIC POWER GENERATION STRATEGIES

Takashi Hashiba

This research investigates whether or not people's awareness of photovoltaic power generation (PVPG, a form of renewable energy) and nuclear power generation was shaped through a consideration of their effectiveness in the prevention of global warming and the impact of these energy forms on lifestyle. It also investigates whether a positive aspect of nuclear power generation—zero CO_2 emission—is a factor important enough to convince people to overcome their concerns about it. Results show that attitudes toward the introduction of PVPG with its associated social costs were related to two factors: the environmentally friendly image of PVPG and concerns about deterioration in the standard of living. Hardly any relationship was found between the fact that nuclear power generation never discharges CO_2 and an awareness of energy and environmental issues.

INTRODUCTION

Thanks to the Third Conference of the Parties (COP3) to the United Nations Framework Convention on Climate Change, held in Kyoto, the Japanese people have an increased interest in issues of global warming. After COP3 the national government announced an action plan to achieve Japan's target to reduce greenhouse gases (by 6% below 1990 levels) as set out in the Kyoto Protocol. The measures in the action plan are grouped into three key measures: (a) promotion of energy-saving, (b) development of renewable energy, and (c) increase of nuclear power generation. Cutting down the amount of greenhouse gases would focus on these three measures in all countries.

The concrete approaches to these measures taken in Japan include the introduction of a top runner system for home electrical appliances, which will require that new products exceed the performance standards in energy efficiency of products currently on the market; the extension of a subsidy for the introduction of photovoltaic power generation (PVPG); and increased efforts to inform the public that nuclear power generation does not discharge CO_2. However, none of the key measures have made the progress planned. In response to this situation, the government released a revised action plan last year, in which the target of nuclear power plant expansion was set lower, thereby encouraging energy-saving to an even greater extent.

The national government and industry have been publicly campaigning on a continual basis in order to deepen people's understanding of these measures to be implemented. Yet despite these efforts, the public campaign has not led to real progress toward successful fulfillment of these measures. How do people perceive the messages from the national government and industry? What do they make of the message that nuclear power generation is an environmentally friendly energy source that does not release CO_2 during the power generation process? Although there are concerns about potential hazards, doesn't this advantage persuade some people to accept additional NPPs in order to prevent global warming?

RESEARCH QUESTIONS

In consideration of the above circumstances, this research was conducted with two objectives. First, it explored whether people form attitudes toward the three measures —namely, energy-saving, renewable energy, and nuclear power generation—after trying to evaluate their environmental effects and the inconveniences that accompany their respective implementation. Second, it examined whether people are now more convinced that nuclear power generation has the potential to help prevent global warming.

RESEARCH METHOD

Defining the research objectives

Before conducting the survey it was necessary to define what should be clarified in concrete terms. The adoption of just one of these three measures would not suffice to solve our energy and environmental issues. Moreover, these measures are not independent of each other. The promotion of energy-saving reduces the share of energy supply that must be changed to other energy sources discharging less CO_2, but it also clearly leads to a considerable deterioration in the standard of living. Increased generation of new forms of energy, particularly photovoltaic (PV) power and wind power, is an attractive alternative to the inconveniences of energy-saving or additional nuclear power plants, which raise concerns about severe accidents. Yet in the midst of a recession, people cannot afford more costly energy sources. It seems that a drastic reduction in the amount of CO_2 emissions inevitably requires the building of more nuclear power plants. However, there is no positive reason why local people living in host regions should accept additional nuclear power plants for the benefit of people in urban areas, who seem to be wasting electricity (Kitada & Hayashi, 1999).

An individual must give consideration both to the effects of improving energy and environmental issues (i.e., the advantages of the measures) and to the inconveniences associated with implementation of the measures, which affect one's lifestyle (i.e., the disadvantages of the measures). The individual then tries to decide how much he or she should accept each measure and brings them together to form a whole picture. Therefore, before deciding on one's attitude toward each measure, it is to some extent necessary to go through a process of comparing and evaluating the advantages and disadvantages of each measure, based on one's knowledge of energy and environmental issues.

In other words, the first objective of this research is addressed by determining whether there is any relationship between the advantages and disadvantages of each measure, and how the advantages and disadvantages of each measure are related to people's awareness of energy and environmental issues. The second objective is tackled by identifying the relationship between people's awareness of energy and environmental issues and their attitude toward nuclear power generation, as determined by the process mentioned above.

Model of latent variables for structural equation modeling

In using an analysis based on structural equation modeling (SEM), we built a model of the relationships between people's awareness of energy and environmental issues; the advantages and disadvantages of

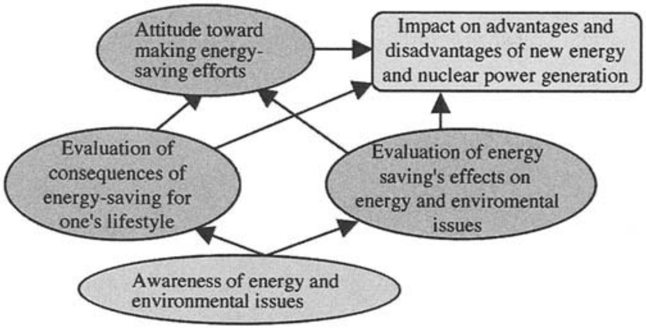

Figure 14.1 Assumed model for energy-saving.

energy-saving, renewable energy, and nuclear power generation in tackling energy and environmental issues; and people's attitudes toward each measure. In this model, people's awareness of energy and environmental issues, the advantages and disadvantages of each measure, and so on are treated as latent variables. Each latent variable is linked with some observed variables. We conducted a questionnaire survey based on the items related to these observed variables.

When we built the model, the following assumptions guided the relationships set among latent variables. (Renewable energy was represented by PVPG, because people are more familiar with it.)

1. The latent variable for the starting point of the structural equation model is "awareness of energy and environmental issues." The three key measures are necessary to solve energy and environmental issues. This step in building the model was the most natural assumption.
2. The evaluation of advantages and disadvantages of each measure affects people's "attitude toward the measure." When one tries to decide to what extent one accepts a measure, one must give consideration to its advantages and disadvantages. Moreover, these advantages and disadvantages are also evaluated against each other.
3. The evaluation of advantages and disadvantages of a measure affects that of another measure, and vice versa. When attempting to decide how one might combine key measures, to some extent one must engage in a process of comparing and evaluating the advantages and disadvantages of each measure, based on one's knowledge and experience of energy and environmental issues. Eventually, the evaluations of different measures are mutually reflected. For example, people who installed PVPG systems claimed, "My family began to make more energy-saving efforts after looking at the power indication of power generation system" (Japan Photovoltaic Energy Association, 1999). However, in order to avoid creating a circular model, the direction of impact was considered to be energy-saving $\Rightarrow$ renewable energy (PVPG) $\Rightarrow$ nuclear power generation, given that the evaluation of a familiar energy source affects that of an unfamiliar one. Priority was given to energy-saving because PVPG is still uncommon. Indeed, only one respondent had installed a PV system. Figure 14.1 shows the assumed model for energy-saving.

Questionnaire survey

A questionnaire survey was conducted in the year 2000. The selection of males and females aged 20 years or older from Japan's Kansai region was based on stratified two-stage random sampling and amounted to 1, 500 individuals. The survey period ran from September 7–24, 2000. Questionnaires were handed out to subjects and later collected by investigators. The number (ratio) of effective respondents was 1,056 (70. 4%).

Confirmation of latent variables through factor analysis

Factor analysis was conducted with respect to the observed variables in order to confirm latent variables. The latent variables for SEM analysis, shown in Table 14.1, were decided based on the results of this factor analysis. The observed variables corresponding to latent variables are shown in Table 14.2.

Table 14.1 Latent variables reviewed by factor analysis

	Before questionnaire survey	**After questionnaire survey**
	Awareness of energy and environmental issues	Awareness of energy and environmental issues
Energy-saving	Attitude toward making energy-saving efforts	Attitude toward making energy-saving efforts
	Evaluation of energy-saving's effects on energy and environmental issues	Evaluation of energy-saving effects
	Evaluation of consequences of energy-saving for one's lifestyle	Doubts about energy-saving Concerns about deterioration in the standard of living due to energy-saving
Renewable energy	Attitude toward using renewable energy	Personal motivation to use photovoltaic (PV) power
		Attitude toward introduction of photovoltaic power generation (PVPG) with its associated social costs
	Evaluation of renewable energy's effects on energy and environmental	Environmentally friendly image of PVPG
	Evaluation of consequences of using renewable energy for one's lifestyle	Concerns about solar-panel disposal problems (a)
Nuclear power generation	Attitude toward using nuclear power generation	Evaluation of nuclear power generation's environmental characteristics, availability, and necessity (b)
	Evaluation of nuclear power generation's effects on energy and environmental issues	
	Consequences of nuclear power generation for actual lifestyle	Doubts about nuclear technologies
		Concerns about risk of nuclear power generation

	Before questionnaire survey	After questionnaire survey
	Awareness of energy and environmental issues	Awareness of energy and environmental issues

Note: (a) This variable was not used in the SEM analysis because there was no convergence in the calculation. (b) Because the variables for attitude and effect were not separated, for the sake of simplicity only observed variables for effect factors (environmental characteristics and availability) were utilized in the SEM analysis.

Table 14.2 Latent and Observed Variables

	Latent variables	Observed variables
	Awareness of energy and environmental issues	Environmental conservation has higher priority than economic development. It is inevitable that energy production must increase to maintain standard of living. Japan has a responsibility to achieve targets set out at the Third Conference of the Parties to the Convention on Climate Change.
Energy-saving	Attitude toward making energy-saving efforts	Engaged in energy-saving. It is burdensome to implement daily energy-saving. Implement energy-saving to a degree.
	Evaluation of energy-saving effects	Implementation of energy-saving contributes to environmental conservation. Implementation of energy-saving reduces domestic expenses. Energy-saving contributes to global environmental conservation.
	Doubts about energy-saving	It is tedious to always take energy-saving into consideration. Energy-saving is unnecessary if energy sources are clean. The share of energy needs that can be reduced is very low.
	Concerns about deterioration in the standard of living due to energy-saving	Some accidents and social concerns result from forced energy-saving. Forced energy-saving damages the economic potential of Japan. Energy-saving, if not practiced voluntarily, should be mandated and enforced.
Renewable energy	Personal motivation to use photovoltaic (PV) power	I would use PV power if it became less expensive. If asked, I would allow PV power to be installed on my roof free of charge.
		I would apply for green pricing.
	Attitude toward introduction of photovoltaic power generation (PVPG) with its associated social costs	PVPG is a measure that all people agree with, even if they must pay for it. PVPG should be promoted even if the public bears the burden of the cost.

	Latent variables	Observed variables
	Environmentally friendly image of PVPG	Concrete and effective environmental contribution. Neighbors' awareness of energy and environmental issues is increased.
Nuclear power generation	Evaluation of nuclear power generation's environmental characteristics, availability, and necessity	The amount of CO_2 emission in nuclear power generation is lower than that in PVPG. Excellent generation method from an economic perspective. Quasi-domestic energy.
	Doubts about nuclear technologies	It is impossible to ensure the safety of nuclear plants with the use of current technologies. It is impossible to safely dispose of high-level radioactive wastes.
	Concerns about risk of nuclear power generation	Radioactive releases to surroundings also occur during operation.
		There is a possibility that an accident like the one in Chernobyl will occur in Japan.

RESULTS

General trends

Figure 14.2 shows the results of an SEM analysis, including all data from respondents. The item "concerns about solar-panel disposal problem" was excluded from the SME analysis because there was no convergence in the calculation. The paths indicated have standardized partial regression coefficients with a significant level of 1% or above and an absolute value of 0.2 or above.

Energy-saving

There is no direct path from "awareness of energy and environmental issues" to "attitude toward making energy-saving efforts": they are connected via "doubts about energy-saving." Moreover, there is no link from "evaluation of energy-saving effects" to "attitude toward making energy-saving efforts." It seems that people's "attitude toward making energy-saving efforts" is dependent on their belief that such behavior should be expected, rather than a belief that it helps protect the environment. Of course, individuals who are more aware of energy and environmental issues do not hesitate to practice energy-saving; they also view energy-saving more positively and have fewer "concerns about deterioration in the standard of living due to energy-saving."

Renewable energy (PVPG)

There are two paths to "personal motivation to use PV power": one direct path from "awareness of energy and environmental issues" and an indirect path via "environmentally friendly image of PVPG." This result indicates that individuals who are more aware of energy and environmental issues are more likely to be interested in using PV power.

On the other hand, there are two indirect paths from “awareness of energy and environmental issues” to “attitude toward the introduction of PVPG with its associated social costs”: one goes through the “environmentally friendly image of PVPG,” and the other goes through “concerns about deterioration in the standard of living due to energy-saving.” The item “environmentally friendly image of PVPG” relates to the evaluation of advantages of the measures, and “concerns about deterioration in the standard of living due to energy-saving” relates to participants’ sensitivity to the disadvantages of the measures. It indicates that attitudes toward the introduction of PVPG and its associated social costs depend on the strength of individuals’ views about its advantages and disadvantages.

Nuclear power generation

There is little correlation between “awareness of energy and environmental issues” and “evaluation of environmental characteristics and availability of nuclear power generation,” for they are linked via “doubts about nuclear power technology” and “concerns about risk of nuclear power generation.” These two negative latent variables were dominant in the “evaluation of environmental characteristics and availability of nuclear power generation.” Unfortunately, an awareness of energy and environmental issues was not a strong enough factor to improve the evaluation of the environmental characteristics and availability of nuclear power generation.

Relationship between energy-saving, renewable energy, and nuclear power generation

Although there are some paths between the latent variables of energy-saving and PVPG, there is hardly any path between the latent variables of energy-saving and nuclear power generation or the latent variables of PVPG and nuclear power generation. It is fair to say that people hardly compare the advantages and disadvantages of nuclear power generation with those of energy-saving or PVPG.

Trends by age group

Figures 14.3 to 14.5 show the results of an SEM analysis using the data of respondents in the age groups 20–39, 40–59, and 60 or above. It was found that there are clear differences in attitude among the different age groups.

Energy-saving

The link between “awareness of energy and environmental issues” and “attitude toward making energy-saving efforts” differs according to age group. Whereas this link runs through “evaluation of energy-saving effects” among people 60 years or older, it runs through “doubts about energy-saving” among younger people. In fact, older people are more actively engaged in energy-saving, a circumstance thought to be reflected in this result.

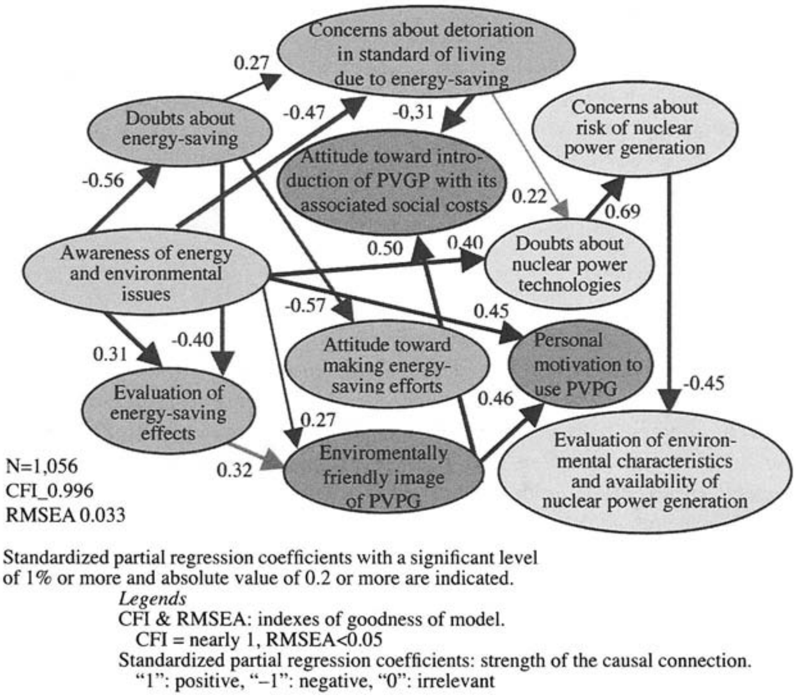

Figure 14.2 Structural relation of attitudes toward energy-saving, renewable energy, and nuclear power generation.

Renewable energy (PVPG)

There was no difference among age groups in the tendency toward personal motivation to use a PVPG system. However, in the case of links to "attitude toward the introduction of PVPG with its associated social costs" from "awareness of energy and environmental issues," the tendencies of the younger and the older generations seem to be contrary. Whereas the link through "concerns about deterioration in the standard of living due to energy-saving" is stronger among people in the 20–39 age group, the link through "environmentally friendly image of PVPG" is stronger among those aged 60 or above. The older people become, the more emphasis they place on the effects of environmental conservation than on conveniences for their own lifestyle.

Nuclear power generation

The correlation between "concerns about risk of nuclear power generation" and "evaluation of environmental characteristics and availability of nuclear power generation" is smaller among people 20–39 years old, though the overall tendency with respect to nuclear power generation is the same.

CONCLUSION

Many people believed that energy-saving was good in itself and something that simply should be expected, not something that was done based on an awareness of energy and environmental issues. Older people, however, tend to make energy-saving efforts to contribute to environmental conservation.

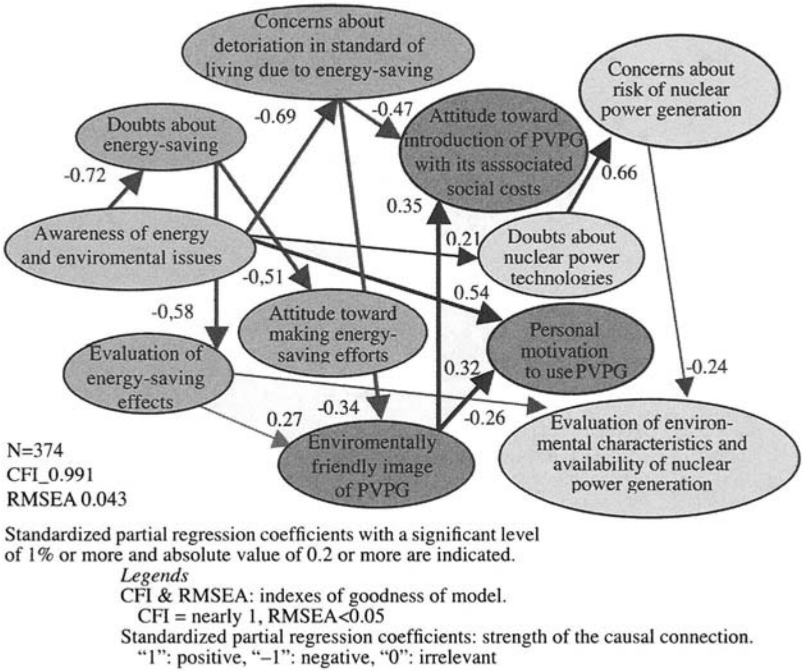

Figure 14.3 Structural relation of attitudes toward energy-saving, renewable energy, and nuclear power generation: 20–39 age group.

With regard to PVPG, there was a strong relationship between personal motivation to use PV power and awareness of energy and environmental issues. Attitudes toward the introduction of PVPG with its associated social costs were related to two factors: the environmentally friendly image of PVPG and concerns about deterioration in the standard of living due to environmental preservation activities, such as those arising from energy-saving or sharing social costs. Older people tended to attach more importance to an environmental contribution than to concerns about deterioration in the standard of living.

There was no evidence that the evaluation of energy-saving effects or PVPG affected the evaluation of the environmental characteristics and the availability of nuclear power generation. It should be noted that nuclear power generation is still too specialized for people to discuss the advantages and disadvantages of it; the same applies for the issues of energy-saving and renewable energy.

Doubts about nuclear power technology and concerns about accidents decisively undermine the evaluation of environmental characteristics and the availability of nuclear power generation. As a result, people's awareness of energy and environmental issues was not at all related to a greater appreciation of the evaluation of environmental characteristics and availability of nuclear power generation. Despite efforts made by the government and industry, the argument that nuclear power generation is a rational solution to global warming is not yet convincing enough for people to overcome their doubts about nuclear power technology and their concerns about severe accidents. Hence, they are not more likely to be in a position to accept additional nuclear power plants.

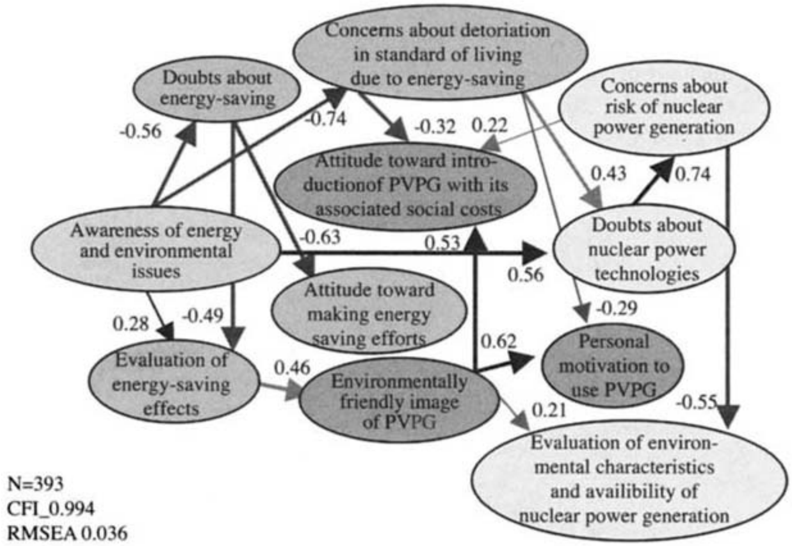

Figure 14.4 Structural relation of attitudes toward energy-saving, renewable energy, and nuclear power generation: 40–59 age group.

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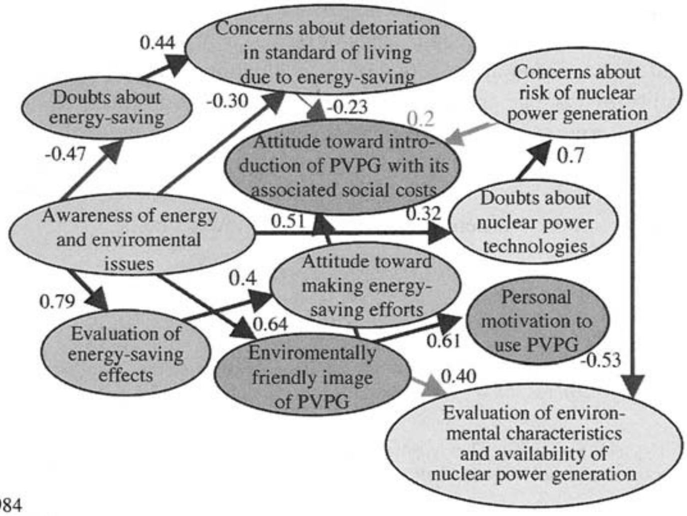

N=289
CFI_0.984
RMSEA 0.056

Standardized partial regression coefficients with a significant level of 1% or more and absolute value of 0.2 or more are indicated.

Legends
CFI & RMSEA: indexes of goodness of model.
CFI = nearly 1, RMSEA<0.05
Standardized partial regression coefficients: strength of the causal connection.
"1": positive, "–1": negative, "0": irrelevant

Figure 14.5 Structural relation of attitudes toward energy-saving, renewable energy, and nuclear power generation: age group 60 years and older.

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