NUREG/CR-5437

Organization and Safety in Nuclear Power Plants

Prepared by A. A. Marcus, M. L. Nichols, P. Bromiley,
J. Olson, R. N. Osborn, W. Scott, P. Pelto, and
J. Thurber

Strategic Management Research Center
University of Minnesota

Prepared for
U.S. Nuclear Regulatory Commission

AVAILABILITY NOTICE

Availability of Reference Materials Cited in NRC Publications

Most documents cited in NRC publications will be available from one of the following sources:

1. The NRC Public Document Room, 2120 L Street, NW, Lower Level, Washington, DC 20555

2. The Superintendent of Documents, U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20013-7082

3. The National Technical Information Service, Springfield, VA 22161

Although the listing that follows represents the majority of documents cited in NRC publications, it is not intended to be exhaustive.

Referenced documents available for inspection and copying for a fee from the NRC Public Document Room include NRC correspondence and internal NRC memoranda; NRC Office of Inspection and Enforcement bulletins, circulars, information notices, inspection and investigation notices; Licensee Event Reports; vendor reports and correspondence; Commission papers; and applicant and licensee documents and correspondence.

The following documents in the NUREG series are available for purchase from the GPO Sales Program: formal NRC staff and contractor reports, NRC-sponsored conference proceedings, and NRC booklets and brochures. Also available are Regulatory Guides, NRC regulations in the *Code of Federal Regulations*, and *Nuclear Regulatory Commission Issuances*.

Documents available from the National Technical Information Service include NUREG series reports and technical reports prepared by other federal agencies and reports prepared by the Atomic Energy Commission, forerunner agency to the Nuclear Regulatory Commission.

Documents available from public and special technical libraries include all open literature items, such as books, journal and periodical articles, and transactions. *Federal Register* notices, federal and state legislation, and congressional reports can usually be obtained from these libraries.

Documents such as theses, dissertations, foreign reports and translations, and non-NRC conference proceedings are available for purchase from the organization sponsoring the publication cited.

Single copies of NRC draft reports are available free, to the extent of supply, upon written request to the Office of Information Resources Management, Distribution Section, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

Copies of industry codes and standards used in a substantive manner in the NRC regulatory process are maintained at the NRC Library, 7920 Norfolk Avenue, Bethesda, Maryland, and are available there for reference use by the public. Codes and standards are usually copyrighted and may be purchased from the originating organization or, if they are American National Standards, from the American National Standards Institute, 1430 Broadway, New York, NY 10018.

NUREG/CR-5437
RX, 1S, 9U

Organization and Safety in Nuclear Power Plants

Manuscript Completed: April 1990
Date Published: May 1990

Prepared by
A. A. Marcus, M. L. Nichols, P. Bromiley,
J. Olson, R. N. Osborn, W. Scott, P. Pelto, and
J. Thurber

Strategic Management Research Center
University of Minnesota
Minneapolis, MN 55455

Prepared for
Division of Systems Research
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555
NRC FIN D2084

ABSTRACT

Perspectives from industry, academe, and the NRC are brought together in this report and used to develop a logical framework that links management and organization factors and safety in nuclear power plant performance. The framework focuses on intermediate outcomes which can be predicted by organizational and management factors, and which are subsequently linked to safety. The intermediate outcomes are efficiency, compliance, quality, and innovation. The organization and management factors can be classified in terms of environment, context, organizational governance, organizational design, and emergent processes. Initial empirical analyses were conducted on a limited set of hypotheses derived from the framework. One set of hypotheses concerned the relationships between one of the intermediate outcome variables, efficiency, as measured by critical hours and outage rate, and safety, as measured by 5 NRC indicators. Results of the analysis suggest that critical hours and outage rates and safety, as measured in this study, are not related to each other. Hypotheses were tested concerning the effects on safety and efficiency of utility financial resources and the lagged recognition and correction of problems that accompanies the reporting of major violations and licensee event reports. The analytical technique employed was regression using polynomial distributed lags. Results suggest that both financial resources and organizational problem solving/learning have significant effects on the outcome variables when time is properly taken into account. Conclusions are drawn which point to this being a promising direction to proceed, though with some care, due to the current limitations of the study.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

Each of the members of the team which performed this research wish to express their appreciation to a number of people who made important contributions throughout the life of the project. Special gratitude is due the U.S. NRC personnel whose on-going support and guidance has been invaluable, especially Dr. Erasmia Lois, Program Manager for the project, Dr. Tom Ryan, Dr. Franklin Coffman, Joel Kramer, Mark Williams, and Steve Stern. They have provided critical reviews of our work at various stages, enhanced the potential impact of the research by attempting to keep us focused on the broader needs of the NRC, and have facilitated communication within NRC as well with other organization factors researchers.

We also wish to thank a group of renowned scholars in management and organization from academe. Professor Andrew Van de Ven of the University of Minnesota was a full partner in the early stages of the project and collaborated with Dick Osborn in the preparation of Chapter 2. His assistance is greatly appreciated. Together he and Osborn also engaged a larger group of academics who shared their insights regarding factors that may influence nuclear power plant safety, and by doing so helped shape our thinking throughout the project. For this we are grateful to Professors Janice Beyer, Kim Cameron, Larry Cummings, Luther Gerlach, George Huber, Todd LaPorte, Howard Kunreuther, Paul Lawrence, Arie Lewin, Charles Perrow, Karlene Roberts, William Starbuck, Karl Weick, and Aaron Wildavsky.

Dr. Kathryn Baker, of Battelle Human Affairs Research Center, and Aru Mukerjee, of the University of Minnesota, provided very able research assistance to the project team. Their contributions are greatly appreciated. Finally, we were served with remarkable professionalism and patience by Sharon Genzler and Robin Maxwell, of the Strategic Management Research Center at the University of Minnesota. They handled all of the administrative work of the project and produced the manuscript. They did a terrific job.

EXECUTIVE SUMMARY

The research in this report brings to bear NRC, industry, and academic perspectives to develop a logical framework which links management and organization factors to safety in nuclear power plants. The purpose of the framework is to guide development of hypotheses which can be subsequently tested empirically. The present project includes an initial empirical examination of a subset of variables identified in the framework, as a means to begin validating the framework as a whole as well as to begin screening candidate indicators for eventual use in diagnosis and prediction.

After introducing the approach and providing an overview of results in Chapter 1, the guiding framework which links management and organization factors and safety is developed in Chapter 2. Four intermediate outcomes linked to safety are derived from theory and practice; they are (1) efficiency, (2) compliance, (3) quality, and (4) innovation. Efficiency is the ratio of inputs to outputs, the rate of a desired outcome over time or the amount of an output as a percent of some theoretical maximum. Efficiency measures frequently used in the nuclear power industry include estimates of availability, reliability, critical hours, and outage rates. With greater efficiency, the system is assumed to be operating more as its designers intended. The relative emphasis on efficiency in combination with or in contrast to other system goals influences overall safety. Compliance refers to the extent to which the utility, one of its units, or a particular employee follows normative prescriptions. Quality is an expression of excellence in systems, people, procedures, and administrative systems. High quality typically connotes that there is additional capacity available to deal with normal operations and emergency conditions. Finally, innovation is the development and application of new knowledge. The more known about the technology and how it can be managed, the more likely changes can be made to reduce the chances and the consequences of an accident.

Based upon both academic literature and NRC research, key management and organizational factors are proposed that are expected to be linked with the four intermediate outcomes of efficiency, compliance, quality, and innovation. Organizational learning and problem solving capacity is singled out and developed in depth as possibly representing a central explanation for the intermediate outcomes.

In Chapter 3, the intermediate outcomes are further refined. Efficiency here is related to the allocation of scarce resources. The more efficiently resources are allocated, the more the plant will be able to provide a broad range of support to operations and maintenance, and the more management attention is available to identify and resolve current and future problems. Compliance pertains primarily to human performance, and central issues here

concern the appropriateness of standards in their relation to safety as well as the management and organization strategies needed to motivate, monitor, and reward compliance. Quality is understood from the perspective of the performance of the hardware, which requires examination of both component reliability and design integrity at the system level. Finally, innovation is linked to problem solving capacity. The central argument is that knowledge of past experience supports richer understanding of current problems and their implications.

In Chapter 5 industry efforts to monitor performance are reviewed. Four of the ten indicators proposed by INPO in 1985 relate specifically to efficiency. None of the INPO indicators directly addresses management and organization, although they may be indirectly related. Eighteen indicators used by individual utilities are also reviewed. These indicators are seen as efforts to collect information for problem solving and organizational learning--specifically for problem identification, prevention, and mitigation.

The empirical work undertaken in this project, though limited in scope, was viewed as a means to begin validating the framework and screening some of the key variables. Attention was focused on those parts of the framework that enable hypotheses to be constructed regarding the preconditions for problem solving, and the role of problem solving capacity in producing safety. The analysis consists of regressions using polynomial distributed lags. Safety measures used in the analysis are SCRAMS, significant events, forced outages, safety system failures, and safety system actuations. The independent variables are region, reactor supplier, number of plants per utility, age, size, number of major violations, LERs, utility return on assets and utility debt to equity ratio. Results suggest that financial resources and organizational problem solving and learning as measured by the lagged recognition and correction of problems that accompanies the reporting of major violations and LERs have significant effects on the safety and efficiency measures when time is properly taken into account. The tests and results are further described in the Introduction in Chapter 1, and they are fully developed in the empirical analysis in Chapter 4.

This project represents Phase I of a multi-phase undertaking. Phase I is intended to provide a theoretical foundation and a series of propositions which link management and organization factors to safety. It begins to empirically test some key variables and relationships that may ultimately lead to the development of useful leading indicators of safety. Additional tests will be carried out in Phase II where the framework set forth in this report will be further refined and developed.

The conclusions so far are that the framework developed in this project appears promising, based on triangulation with current industry practice, NRC research and experience, and academic research. Initial empirical tests of hypotheses derived from the framework support further work in this direction.

1.0 INTRODUCTION

The overall purpose of this project is to develop organizational effectiveness indicators for use by NRC (see Figure 1.1). In Phase I a logical framework has been developed. Grounded in appropriate theory, it enables identification of management and organizational factors which may relate to safety in nuclear power plant performance. In Phase I, efforts also have been made to identify a small set of candidate indicators and empirically examine them. In Phase II additional empirical tests will be carried out. The empirical tests in Phase I represent an initial effort to validate the overall framework, which ultimately is intended to yield a set of indicators for diagnostic use by the NRC.

Many previous studies have concluded that management and organization factors are associated with the safety of nuclear power plants (for example, see the detailed case studies of the Three Mile Island accident: NRC, 1979; Kemeny, 1979; Senate Subcommittee on Nuclear Regulation, 1980; for more recent references see: Ryan, 1988; National Academy of Sciences, 1988; Reason, 1988; and Hansen, Winje, Beckjord, et. al., 1989). If good indicators of management and organization were available, NRC, as well as plant and utility management would be in a better position to anticipate potential problems and to do something about them.

This chapter describes the work the project team undertook and provides a summary of what has been accomplished. The first section describes what the project team did and how this report is organized. Section 1.2 attempts to distinguish the broad field of management and organization indicators from other types of indicators the NRC and the industry have been tracking over time. Section 1.3 describes the derivation of a logically supported group of prospective management and organization indicators in this project. Section 1.4 describes the testing of a small set of these indicators. Section 1.5 summarizes the conclusions that can be drawn from this work.

1.1 Description of the Project and Organization of the Report

To meet the objectives of the project, a team was assembled which has the capability of contributing three distinct perspectives to the understanding of performance indicators at nuclear power plants (Figures 1.2 and 1.3). These perspectives were industry, NRC, and academic, which were viewed as essential to developing a framework and ultimately identifying candidate management and organization indicators that have theoretical, practical, and empirical validity. The results of the team members' efforts to bring these perspectives to bear are presented and integrated in this report.

To identify useful and potentially valid management and organization indicators, a number of steps have been taken. First, the extensive literature on organization and management has been

Figure 1.1

Project Objectives:

Develop Organizational
Effectiveness Indicators

Phase I: Develop logical framework that ties factors of organizational performance to safety

Phase II: Empirically test factors to develop useful performance indicators

Figure 1.2

Phase I Objectives

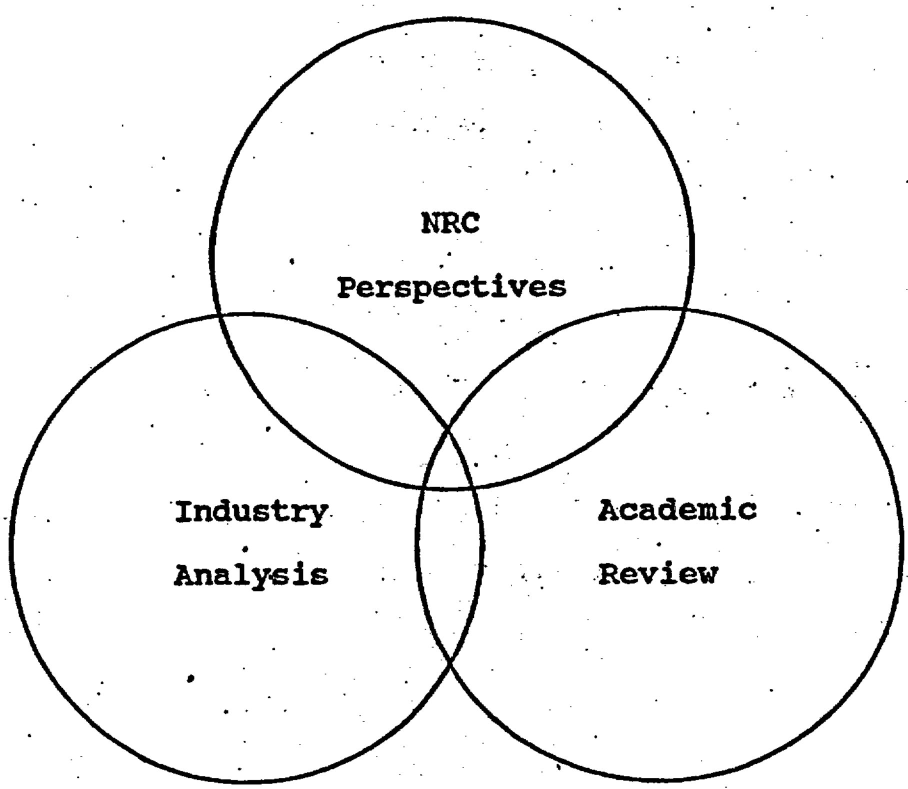
Phase I: Developing logical framework that links Organizational performance factors to safety

* Integrated perspectives from industry practice, NRC research and experience, and academic research

* Examined limited set of candidate management and organization indicators

Figure 1.3

Integrated Contributions from NRC,
Industry and Academe



Preliminary Empirical

Investigation

critically reviewed, and from that a framework and a set of concepts that may prove useful in explaining safety in nuclear power plant performance has been developed. The results of this critical review, carried out by Richard Osborn of Wayne State University, with the assistance of Andrew Van de Ven of the University of Minnesota, are found in Chapter 2 of this volume. To help in this review, Osborn and Van de Ven interviewed a select group of leading management scholars.

Second, NRC studies on the organization and management of nuclear power plants have been reviewed and NRC staff familiar with NRC's efforts in this area have been interviewed. Since there is overlap between NRC and academic studies, the purpose of reviewing the NRC studies and conducting the interviews with NRC staff has been to refine and extend the framework introduced in the second chapter. In Chapter 3, the framework presented in Chapter 2 is operationalized in terms of hypotheses and candidate indicators that, once empirically tested, can be useful to the NRC. The review of NRC studies and interviews with NRC staff were carried out by James Thurber, of American University, and Jon Olson, of the Battelle Human Affairs Research Center, with the assistance of Kathryn Baker from Battelle.

Third, an integrative chapter has been written which relies on the framework in Chapter 2 and data readily accessible to the research team (only data available in computer usable form were used) to screen a number of candidate management and organization indicators that NRC might eventually develop for diagnostic and other purposes. Results of the empirical analysis are presented in the fourth chapter. Empirical studies reported in Chapter 4 were conducted by Alfred Marcus, Philip Bromiley, and Mary Nichols of the University of Minnesota.

Fourth, the performance indicators used by industry, and their relationship to management and organization have been reviewed. The results of this review, carried out by Walter Scott and Peter Pelto of Battelle's Pacific Northwest Laboratories, are reflected in Chapter 5 of this volume.

Fifth, the conclusions drawn from the entire project are presented in Chapter 6.

1.2 Developing Candidate Management and Organization Indicators

Before describing the results of the project, it is important to address the meaning of management and organization indicators, how candidate management indicators can be identified, and how they should be evaluated. To address the meaning of management and organization indicators, it is necessary to briefly define management and organization. Management has been defined as working with people to determine, interpret, and achieve organizational objectives by performing such functions as planning,

organizing, staffing, leading, controlling, learning, problem solving, and innovating (Megginson, Mosley, and Pietri, 1983). Organizations are goal directed and deliberately structured social entities. (Daft, 1988). Once people have united to achieve common objectives, they have created a social mechanism capable of doing more than any single person could accomplish alone. Management and organization factors that are of importance are decision-making, centralizing and decentralizing power and authority, coordinating, allocating resources, measuring and rewarding performance, personnel selection, training and development, motivation, and the processes of managing conflict and change. In Figure 1.4, the definition of management and organization developed in Chapter 2 is summarized. The effects of management and organization factors on safety are noted in Figure 1.5.

From NRC's perspective a valid management and organization indicator must demonstrate that it has the ability to predict future safety performance. Without this ability, the indicator would be of little use to the NRC and to nuclear power plant managers, and it would be unfair to burden either party with using the indicator for diagnostic purposes.

Industry and the NRC routinely trend nuclear power plant performance along a variety of dimensions. Some of these performance indicators only have an indirect relationship to management and organization, but some are more directly related. The relationship between a performance measure and management only becomes apparent when a broad framework showing the logical relationship between well-defined concepts is applied. One of the main purposes of the academic field of study of management is to create such frameworks which relate concepts to each other in a systematic fashion. Concepts represent the similarities in otherwise diverse phenomena (Hoover, 1976). Grounded in theory and past empirical evidence, they are then used for purposes of explanation and prediction. Indicators are the measurable components of concepts that take on different values in different time periods (Labovitz and Hagedon, 1976).

Researchers aiding NRC in identifying performance indicators should avoid the generation of candidate management and organization indicators in an ad hoc fashion, and instead ground their recommendations in a logical framework that establishes theoretical validity and, to some extent, practical utility, before testing for empirical validity. Specific performance indicators routinely followed by industry and the NRC, then, can be related to the concepts found in academic theories. However, the concepts from the academic theories are likely to be broader and more comprehensive than the currently available measures. Therefore, the theories will tend to reveal additional candidate indicators, and, in many cases, show that the information for measuring these indicators is not currently available. To validate the indicators, this information needs to be collected.

Figure 1.4

What is Management and Organization?

Administrative choices by senior management

* Decisions about design, construction, maintenance, decommissioning

* Administrative structures created by senior management to implement decisions

Choices about how to:

* Divide tasks into component parts

* Coordinate efforts of specialized units and individuals

* Control operations

* Insure continued improvement

System of rewards and sanctions (for serving interests of multiple constituencies)

Informal structures that emerge in daily life of organization

Figure 1.5

Effects of Management and Organization
on Safety

Alters probability of human error, understanding, vigilance through such means as:

1) Selection, training, motivation, morale

2) Authorizing expenditures for such items as maintenance, operating experience review, safety engineering

3) Developing realistic and usable procedures

A candidate indicator should possess three properties if it is to be considered valid: (1) a logical relationship to safety that can be derived from the framework and concepts that have been applied; (2) an empirical relationship to safety that derives from statistical tests that show that the candidate indicator predicts safety; and (3) the ability to meet essential measurement standards such as non-susceptibility to manipulation, comparability, and independence from each other. Even when an indicator has these properties a number of qualifications have to be kept in mind. First, just as there are different approaches to designing and building nuclear power plants so too are there different approaches to the study of organization and management. Different frameworks can be applied (see Morgan, 1986), and while these frameworks share some concepts and have much in common there still are differences between them which will affect the conclusions reached and the implications drawn. Second, with regard to empirical tests, caution must be employed in interpreting the results. Empirical tests show tendencies; they indicate that as more of X is present, more of Y is likely to be present. They are not deterministic (more of X does not mean that more of Y has to be present, just that there is a greater probability that more of Y will be present). Moreover, empirical tests are bound by past data. They simply show that certain relationships prevailed in the past. Whether these same relationships will prevail in the future can only be determined through longitudinal study. There is no guarantee that the system will operate in the same way in the future. Fundamental shifts in key factors, introduction of new factors or disappearance of certain factors can change the predicted relationships.

1.3 Deriving Candidate Indicators for Further Consideration

In this section information on how the candidate management and organization indicators used in this project were chosen will be presented. We started with NRC's mission (see Figure 1.6) and NRC's logic model of safety (see Figure 1.7) and tried to link management and organization items to this framework.

The present efforts have been geared toward creating a logical framework in which safety is directly connected to management and organization. An example of the effect of organization and management on safety is provided in Figure 1.8. The logical framework is fully developed in Chapter 2.

Four intermediate outcomes--efficiency, compliance, quality, and innovation are the central concepts which are logically related to ultimate safety indicators. These intermediate outcomes are briefly defined and operationalized in Figures 1.9-1.12. Affecting these intermediate outcomes are the organization's environment, context, governance structure, design, and its emergent processes (Figure 1.13). Environment refers to all factors outside the boundaries of the utility such as the national culture, the degree

Figure 1.6

Mission of NRC

NRC Mission =

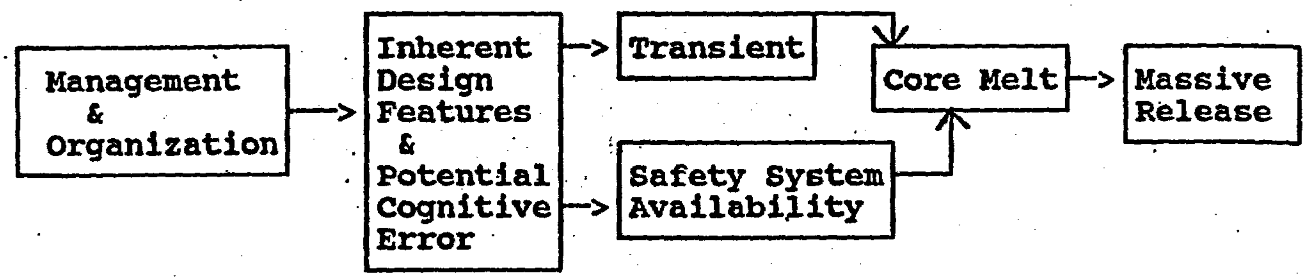
Promote Safety

Prevent Accidents

Protect Public Health

Figure 1.7

Linking Organizational & Management Factors to Safety



Preliminary candidate indicators	Examples of suggested indicators
Initial Phase I analysis	Scrams Sig. events Forced outages Safety syst. actuations Safety syst. failures

* Interoffice Task Force

Figure 1.8

An Example of the Effect of Organization and Management on Safety

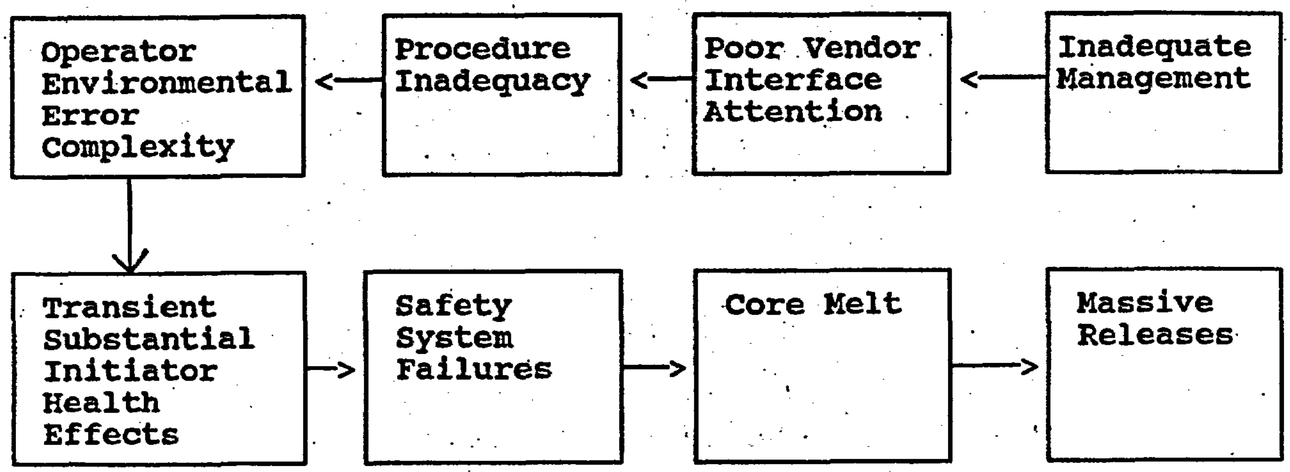


Figure 1.9

Definitions and Operationalization
Of Intermediate Outcomes

Efficiency --

Ratio of inputs to outputs (including resource allocation)
Rate of desired outcome over time

e.g. critical hours

Amount of output as percent of theoretical maximum

e.g. outage rate
availability rate

Figure 1.10

Definitions and Operationalization of Intermediate Outcomes

Compliance --

Degree to which utility, component units, particular employees follow normative prescriptions

* System of rewards and sanctions that motivate compliance
* System to communicate expectations
* System to monitor and correct

e.g. # Inadequate procedure LERs
Procedure violation LERs
Inadequate inspection LERs

Figure 1.11

Definitions and Operationalization of Intermediate Outcomes

Quality --

Excellence in construction and operation

Hardware Performance

e.g. # Design/fabrication LERs
Design based generic safety issues & technical specification revisions
Component failure lers

Human Performance

e.g. Turnover, absenteeism, morale

Figure 1.12

Definitions and Operationalization of Intermediate Outcomes

Innovation --

Development & application of new knowledge

* Good two-way communication
* Effective management information system
* Low number of recurring problems

e.g. Speed of resolution of safety issues
Frequency of repeat failures
Decrease of operational problems for new plants

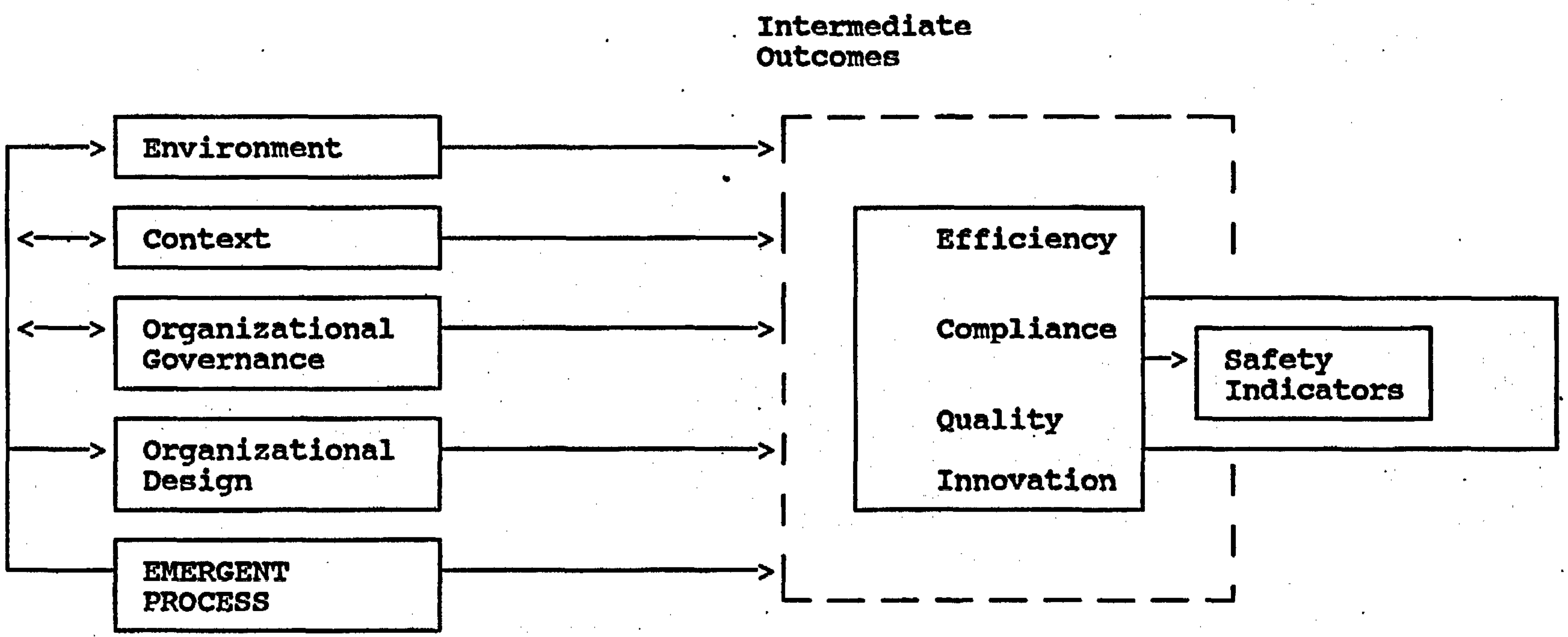
regulation and self-regulation, and the pattern of ownership and control. Context is defined in terms of staff size, budget, and characteristics of the technology. Governance structure is the pattern of authority, influence and managerial behavior sought by senior management. Design refers to the type of administrative structure. It includes such factors as the division of labor, the pattern of control, the means of coordination, and the mechanisms for management and staff development. Emergent processes is the term which characterizes the unplanned continuing dynamics of the organization that enable it to operate with continuity and react to unanticipated conditions. These management and organization concepts can be further specified and can subsequently be developed into indicators, measured, and related to safety. Chapter 2 contains a set of propositions which predict conditions which will lead to particular intermediate outcomes and which also describe the typical conflicts that occur among them.

Emergent processes receive considerable attention in Chapter 2, and figure prominently in the empirical analysis reported in Chapter 4. Emergent processes, the unplanned dynamics of the organization, arise because individuals, not impersonal forces, shape and mold the formal organization, interpret the environment and context, and add variety to that planned into the organization. Figure 1.14 shows the important emergent processes mentioned in the academic literature and previous NRC studies. Many of the concepts in Figures 1.13 and 1.14 cannot be measured or empirically validated with existing data. The concepts for which data were readily available to the research team are shown in Figure 1.15.

In Chapter 3 of this report, suggestions for additional empirical validation of indicators is given. These suggestions are derived from a more inductive approach to identifying both the management and organization factors important to safety, and how these factors can be measured and evaluated. Specifically, a set of measures has been generated through interviews with NRC personnel, and reviews of the NRC literature and key regulatory activities in the area of management and organization. In general, the inductive approach lends support to the theoretical overview in Chapter 2, in that there is considerable overlap in the significance placed on the intermediate outcomes of efficiency, quality, compliance, and innovation, as the links between management and organization and safety. By specifying in more detail the nature of these links, Chapter 3 identifies additional ways to measure the intermediate outcomes, and specific management and organization strategies and characteristics that must be measured before a comprehensive evaluation of management and organization effects on safety can be performed. Many of these strategies and characteristics will require the collection of new data, but they are essential to the development of a practical regulatory approach.

Figure 1.13

Framework for Linking Management and Organizational Factors with Safety



* This model is a revised version of the model found in Osborn et. al. (1983), p. 37.

Figure 1.14

Studies Which Relate Emergent Processes to Safety Indicators*

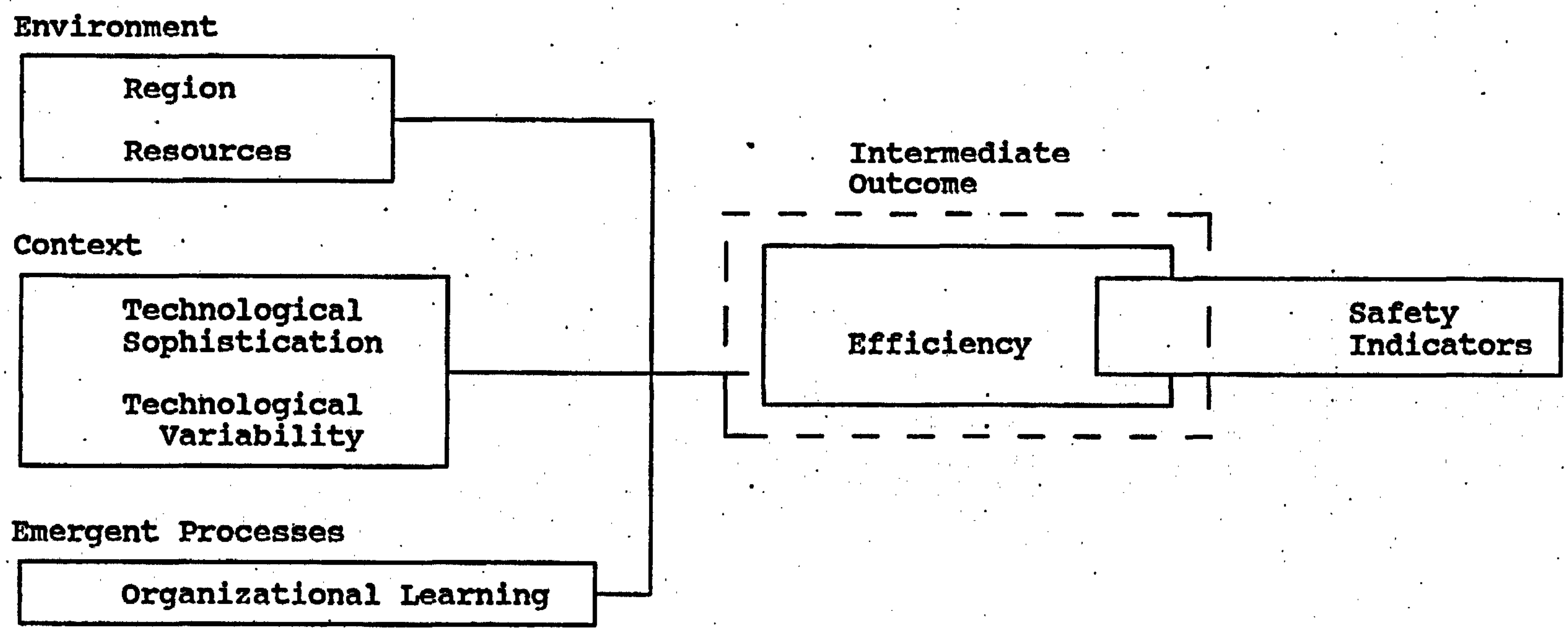
EMERGENT PROCESS

<u>Problem Solving Capacity Organizational Learning</u>	<u>Labor Relations</u>	<u>Cross-Training/Worker Rotation</u>
Weick (1988) Taylor (1985) Bremer (1986)	Bregel et. al. (1985)	Bregel et. al. (1985)
<u>Organizational Culture</u>	<u>Supervisory Relations</u>	<u>Worker Attitudes</u>
Human Synergistics (1987)	Ryan (1988) Komaki et. al. (1986)	Ryan (1988) Taylor (1985)
<u>Relations Between Functional Areas</u>	<u>Administrative Problems/ Human Error</u>	<u>Fatigue/Stress</u>
Wreathall et. al. (1988) Brookhaven (1988) Haber et. al. (1988)	OLSON ET. AL. (1988) OLSON ET. AL. (1986) OLSON ET. AL. (1984)	Ryan (1988)
<u>Plant-Headquarter Relations</u>	<u>Training</u>	<u>Additional Items considered by NRC</u>
Wreathall et. al. (1988) Brookhaven (1988) Haber et. al. (1988)	Wreathall et. al. (1988) Ryan (1988) OLSON ET. AL. (1988) Weick (1988) Taylor (1988)	- Goal setting - Decision making - Performance measuring & reporting -Improvement programs -Personnel qualifications

*Empirical studies are highlighted in capital letters.

Figure 1.15

Factors Examined in Initial Empirical Analysis



From the review of the performance indicators currently used by industry (see Chapter 5), it is apparent that the limitation of these indicators is that they have been developed incrementally over time to deal with specific issues as they have arisen and are not part of a broader logical framework. Moveover, the individual industry indicators are only indirectly linked to management and organization. Nonetheless, an important aspect of these indicators is that they focus on organizational problem solving, that is the means by which utility management identifies and corrects problems.

1.4 Testing a Small Set of Indicators

Attention is now turned to the empirical work carried out in Chapter 4. The results provide support for indicators related to the concept of problem solving capacity. This concept is derived from theories of organizational learning, which have received extensive attention in the academic literature. A complete review of the relevant literature on organizational learning is found in Chapter 4. Some of its more salient features will be briefly summarized here. Problem solving capacity in organizations that run high risk technologies is very important. For example, when first introduced, bridges, natural gas lines, and commercial air travel all appeared to be dangerous. Today, these technologies are accepted and commonplace. By recognizing and dealing with problems that developed in these systems, the number and severity of incidents has been reduced and society is better able to live with the consequences of the residual danger (see Wildavsky, 1988).

Clearly, problem solving is essential in organizations that employ high risk technologies for it leads to the ability to anticipate problems that might arise and to substantially mitigate the consequences. To the extent that members of organizations that manage high risk technologies develop problem solving capacities, the organizations become more effective.

The organization starts with certain core beliefs about action-outcome relations (Duncan and Weiss, 1979), that is, knowledge of the relationship between the organization's actions and various safety outcomes. It has an existing knowledge-base, a paradigm, a way of seeing, or principles governing perception. These are embodied in the organization's pre-operational plans, such as where the reactor should be located, from whom it should be purchased, and how it fits into the corporate structure. If all goes as expected, these plans will not change. However, it is unlikely that the initial knowledge base is perfect. Problems occur and members of the organization realize that there are discrepancies between the organization's performance and the expectations that have been formed about how it should be performing (Downs, 1967).

Problem solving typically involves the processing of information (for example, an accident report) so as to better understand problems that have arisen and their implications. It also requires

that resources be available to do something about the problems that have come to management's attention. Without adequate resources to invest in personnel, training, and capital for continuous refinement and improvement, it is unlikely that managers can take the actions needed to improve performance. For organizational reflection, experience, and problem solving to take place and for new competencies and skills to be introduced, resources to devote to problem solving are essential (Miles, 1982). In short, what the literature on problem solving suggests is that it requires both (1) the ability to spot problems and to diagnose them before they emerge, and (2) the resources to do something about these problems once they develop. Problem solving as a concept also implies (3) a time dimension. It is only over time that the results of problem solving can be observed, if indeed they can be observed at all. Thus, empirical tests conducted in this project have been designed to look at time lags in the relationships between problem solving and performance results.

The two prospective management/organization indicators related to problem solving that were empirically tested were:

(1) utility resources [return on assets (ROA) and debt to equity] assessed against a time frame which reveals their influence on public safety; and

(2) the lagged recognition and correction of problems that accompanies the reporting of major violations and licensee event reports (LERs).

In empirically testing these indicators, reliance has been placed on the previous NRC efforts to create safety indicators. In creating these indicators NRC was concerned with low frequency of transients, high availability of safety systems, inherent design safety, and the potential for cognitive error. The group of safety indicators it selected included (i) automatic scrams while critical, (ii) the total number of significant events, (iii) the forced outage rate, (iv) safety system actuations, and (v) safety system failures (Interoffice Task Group, 1986). These indicators have been used in recent empirical work (e.g. see Olson et. al., 1988) and in the empirical work done in this report.

Tests conducted on utility resources, controlling for region, reactor supplier, age, size, and number of plants per utility show the following results:

1) The more profitable a utility is in 1984, the fewer scrams its plants have in 1985-1987.

2) The higher the debt/equity ratio a utility has in 1984, the fewer scrams its plants have in 1985-1987.

3) The more profit a utility has in 1982 and 1983, the fewer the number of scrams and significant events its plants have in 1985-1987.

4) The higher the debt/equity ratio a utility has in 1983 and 1982, the fewer the number of scrams and significant events its plants have in 1985-1987.

5) The more profit a utility has in 1983, the lower is its forced outage rate in 1985-1987.

6) The higher the debt/equity ratio a utility has in 1982, the fewer safety systems failures its plants have in 1985-1987.

Tests done on LERs and major violations, again controlling for region, reactor supplier, age, size, and number of plants per utility show the following results:

1) The more major violations a plant has in 1985 and 1984, the fewer scrams it has in 1985-1987.

2) The more major violations a plant has in 1985, the fewer the forced outages it has in 1985-1987.

3) The more LERs a plant has in 1983 and 1982, the fewer the significant events it has in 1985-1987.

4) The more LERs a plant has in 1983, the fewer the safety system actuations it has in 1985-1987.

5) The more LERs a plant has in 1982, the fewer the scrams that it has in 1985-87.

While scrams, significant events, forced outages and safety system actuations are predicted with statistical significance, the ability to predict safety system failures with the available data is weak.

When coupled with resources to make changes, problem solving capability is enhanced as a result of information from major violations and LERs. These factors, after an appropriate time lag,

have an influence on the safety indicators of scrams, significant events, and forced outages and safety system actuations. In the short-term, major violations have a significant effect on these safety indicators. For LERs, it is two to three years after the occurrence of LERs that improvements in the safety indicators begin to take place.

1.5 <u>The Conclusions That Can be Drawn From This Report</u>

To sum up the results of this project, eight points will be made:

1) While considerable progress has occurred in the empirical analysis of organizational and management factors as they relate to nuclear power, much still needs to be done. A better explanation of nuclear power plant performance can be achieved by understanding emergent processes. While the theoretical developments in this area are extensive, the factors which relate these theories to nuclear power have not been adequately defined and the variables have not been adequately measured. A particularly useful examination of an emergent process done as a follow-up on the work on organizational problem solving would seek to understand how individual utilities select their own performance indicators, what indicators they do select, and how this process and its outcome (the indicators that have been selected) influence performance.

2) To begin to develop a better data base on organization and management, certain basic information about nuclear power plant organization and management needs to be collected on a regular basis by the NRC and kept current. This information includes figures on staffing (e.g. how many people at the plant and headquarters, in what categories, with what qualifications), budgeting (how much money is being spent for what purposes and by whom), and organization charts.

3) NRC should consider how it can productively store, catalogue, and use the intensive qualitative information that is being gathered about organization and management practices by AEOD and the SALP inspectors. This information has potential for being an invaluable source of information on organization and management practices if it is standardized in some fashion and accumulated.

4) The research in this volume suggests that two indicators hold promise for use by the NRC:

> (1) utility resources [return on assets (ROA) and debt to equity] assessed against a time frame which reveals their influence on public safety; and
>
> (2) the lagged recognition and correction of problems that accompanies the reporting of major violations and licensee event reports (LER).

These indicators are both related to the broader concept of problem solving capacity as it is produced by organizational learning. They are particularly promising because of the role of time, the relatively long lags, and the ability of NRC and the utilities to take corrective action given these long lags. That the availability of resources to make changes emerged as a valid indicator should not be surprising. It confirms the simple but important proposition that utilities have to be able to afford safety, that safety costs money, and that without adequate resources safety cannot be achieved.

5) It should be relatively easy for NRC investigators and enforcement officials to track financial data in tandem with the violations and LER data and to consider the consequences of the interaction between these indicators. Information about violations and LERs is already available to NRC officials. NRC now needs to maintain adequate records on utility financial performance (i.e. profit and debt) so that this information also will be available and so that it can be considered along with the data on problem recognition.

6) However promising the research in organization and management factors has been so far, NRC and private researchers need to move beyond simple categories and easily measurable factors that have been examined thus far toward an analysis of the complex, dynamic processes that take place at nuclear power plants. The amount of variance that can be explained with the existing concepts and data is, in some instances, very great, while in other instances, these concepts and data provide little understanding and explanation of nuclear power plant performance. With the existing concepts and available data, safety indicators such as scrams, significant events, and forced outages are better explained than safety system failures and safety system actuations.

7) It is not enough to say that additional work is needed on the causes of safety outcomes. Better definition and conceptual rigor is required with respect to the safety outcomes themselves. Further validation of management and organization indicators requires that appropriate dependent variables and measures of safety which have been justified and obtained broad acceptance, be available.

8) Even with these reservations mentioned about the limitations of what can be done given the available concepts and data, research into the organization and management factors that influence safety outcomes has been promising and justifies the additional expense of continued involvement in this area.

2.0 DEVELOPING A FRAMEWORK THAT LINKS MANAGEMENT, ORGANIZATION AND SAFETY IN NUCLEAR POWER PLANTS[1]

2.1 Purpose & Introduction

The purpose of this chapter is to develop a framework which links management and organization factors and safety. Popular press accounts of accidents in high risk technologies often attribute the cause of the accident to mistakes by operators and/or their immediate supervisors, faulty equipment, or some combination of the two. Subsequent analyses of these accidents, however, typically suggest that there were a number of precursors to the specific incident. High on the list of precursors is management and organizational factors.

In general, the rationales underlying the importance of management and organization factors are simple. The corporation and its senior managers are legally accountable for the safe performance of the system. The technology is the property of the organization and its senior managers are charged with its care, custody, and control. Senior managers are held accountable, in part, because they are granted the discretion to make important choices concerning the deployment of the technology, including how it will be managed and who will design, construct, operate, maintain and decommission it. In most large organizations senior managers do not actually make technical choices but establish systems for making the decisions and select managers who choose the people who run the plant. Prior work in organizational analysis suggests that some administrative arrangements are preferred to others for specific outcomes (see NUREG/CR-3215 for a review). The administrative choices made by senior management have also been empirically related to outcomes related to safety (See NUREG/CR-3737).

Less obvious are the more subtle consequences of placing a complex technology within a large hierarchical organization where multiple interests must be served if the organization is to survive. Not only do managers and employees act in their own behalf, but they also must serve important additional constituencies. They are rewarded, for instance, if they do, and sanctioned, if they do not, serve the interests of superiors, stockholders, customers, and regulators. The interests of these constituencies are represented

---

[1] Richard Osborn and Andrew Van de Ven wish to thank a distinguished panel of management and organization scholars who graciously contributed their ideas in the development of this chapter. The panel consisted of Professors Janice Beyer, Kim Cameron, Larry Cummings, Luther Gerlach, George Huber, Todd LaPorte, Howard Kunreuther, Paul Lawrence, Arie Lewin, Charles Perrow, Karlene Roberts, William Starbuck, Karl Weick, and Aaron Wildavsky.

in the multiple goals of the corporation and by the different constraints under which it operates.

The administrative systems senior management establishes as well as those that informally emerge from the daily life within the corporation help resolve the conflicts that emerge. In balancing goals that partially conflict, administrative systems designed by management and those that emerge from the organization's informal processes may or may not promote safe operation of nuclear facilities to the extent desired by the public or the public's representatives. Given that partially conflicting goals and constraints exist, managers face difficult choices about how to divide tasks into component parts, coordinate the efforts of specialized units and individuals, control operations and insure that the corporation continues to improve. A number of choices are acceptable; none is truly superior on all criteria.

How the administrative systems function depends on the capabilities of the people in the organization. People operate and can improve upon the administrative system that has been set up by managers. People can expand the capability of the organization beyond the expectations of managers. People limit themselves to operate within administrative constraints and liberate themselves from the constraints. In this way the organization is both a planned system and an emergent process.

2.1.1 Linking Organization and Management Factors to Safety

Organization and management factors are linked to safety in a variety of ways. Management and organizational factors alter the probability of human error, human understanding, and/or human vigilance through mechanisms such as selection, training, motivation and morale (See Morey and Huey, 1988, for a discussion and examples). Managers authorize expenditures for maintenance and hardware replacement and may or may not develop policies (such as preventive maintenance) that keep systems, equipment and components in top operating condition. Management may emphasize the development, testing and improvement of realistic, usable procedures or it may downplay this effort by directing funds and attention to other concerns. Management may make efforts to mitigate the effects of accidents by supporting emergency drills, simulators, related equipment, and mitigation methods; and management may fail to manage security well or may allow illegal diversion of radioactive waste, falsification of operator examinations, the making of material false statements to regulators, the purchase of substandard equipment and components, and other dubious acts.

Just as engineers cannot chart all of the intricate interconnections among technical systems, equipment, and components within a nuclear plant, the attempt to chart all the specific linkages among management and organization factors and safety

yields endless speculations. Instead of charting all the potential linkages, it is more useful to isolate a few potentially important frameworks or causal maps that can incorporate the existing research findings. These frameworks can be used to identify the intermediate outcomes that are likely to be linked to safety and to identify the concepts and factors that explain and predict these intermediate outcomes. Once specified, the items in the causal maps can be investigated.

2.1.2 Analytical Challenges in Linking Organization and Management Factors to Safety

The first element in any framework, then, is safety, and the first challenge is that, beyond an accident, it is necessary to have a consensus regarding what constitutes safe operations and how safety can be measured. The second element in the development of causal maps is management and organization and the second challenge is reaching agreement concerning the definitions and aspects of management and organization which are linked to safety. These are both very substantial challenges. There are often multiple definitions of safety facing nuclear utilities emanating from federal and state authorities as well as other constituents such as nuclear interveners, stockholders, bond holders, etc. There is comparatively little empirical research linking organization and management factors to safety. Thus, much of the discussion on potentially important management and organizational factors must be drawn from outside the nuclear experience. This chapter will discuss these issues in turn; first, the question of safety, and then ways to link management and organization to safety.

2.2 Toward a Definition of Safety

Most agree that safety means that no harm should come from generating electricity when using nuclear technology (see Morey and Huey, 1988 or reviews). It is important to prevent accidents and the release of radioactive materials (see the historical review by Del Sesto, 1983). However, it is not possible to eliminate all risks. Since the consequences of an accident are so dire, it is important to develop indicators that forecast potential problems (see Del Sesto, 1983; Morey and Huey, 1988 among others). The debate over safety may often be seen in discussions of specific operational measures. It is especially difficult to empirically validate measures because accidents involving radiological releases are so rare. Often, technical and engineering estimates are used to support the inclusion of specific types of indicators. Here the literature on management and organization is also employed. The following sections review a number of ways of developing such indicators (Figure 2.1).

Figure 2.1

Methods to Develop Management and Organization Indicators

Technical Models: Proximate Causes

*Accident Scenarios
*Probability of Failure of Separate Systems

Management and Organization: Root Causes

*Retrospective Accident Analysis
*Organizational Analyst's Effectiveness Criteria
*Managerial Criteria

2.2.1 Technical Models

Many prior technical studies of safety have argued that defense-in-depth to prevent accidents and/or uncontrolled radiological releases is the key to operating safety (Nichols and Wildavsky, 1988; Osborn and Jackson, 1988).

Essentially, the logic is to (1) construct accident scenarios, (2) isolate the systems, equipment and components involved in the chain of events, (3) estimate the probability that the systems, equipment and/or components will fail and (4) combine the estimates from all possible accident scenarios under current conditions and under one or a number of upgrades. This logic presumes that the system is technologically deterministic, humanly probabilistic, and amenable to decomposition. For instance, equipment does not fail without a reason and these reasons can be listed, assigned probabilities, and the probabilities can be reduced.

2.2.2 Frameworks Incorporating Management and Organizational Factors

Frameworks that incorporate management and organizational factors take a broader perspective. Management and organization factors are presumed to underlie a series of deficiencies: they are "root causes" rather than proximate causes. Three frameworks for incorporating management and organizational factors may be constructed.

<u>Retrospective Causal Maps</u>. With a retrospective framework, the analyst starts with an identifiable event (e.g., an accident such as TMI) and works backward to assign accountability. Deficiencies are identified and a series of corrective actions are recommended to insure that such "mistakes" do not recur.

This framework has appeal because the deficiencies can be corrected and once fixed the changes apparently insure that another accident will not occur. When supported by regulatory bodies, industry and consultants, the recommendations generated in this fashion have considerable legitimacy. This type of analysis provides a rich source of hypotheses about management and organization. However, it is usually limited to specific cases and rarely incorporates a broader theory or causal model.

<u>Generic Causal Models</u>. Here organizational analysts presume that there are "universal" and "objective" effectiveness criteria. Cameron and his associates (Cameron, 1980; Quinn and Cameron 1983, and Cameron and Quinn, 1988) propose a "Competing Values Framework" which evaluates organizations on a variety of criteria along four axes -- flexibility and control and internal and external focus. Since progress on any of the four dimensions calls for some sacrifice on another dimension, organizations are faced with a

series of paradoxes. A successful organization, then, is one that successfully manages paradox.

This framework, however, over-represents the interests and value judgments of the theorist. It is difficult to place concerns over safety, as expressed by the NRC, into this model without simultaneously subordinating safety into one of the more global goals of the theorist such as productivity or efficiency.

Idiosyncratic Causal Models. These question the existence of universal and objective measures of organizational success (e.g., Van de Ven and Ferry, 1980). In support of this perspective, empirical studies have found that managers use multiple, diverse and idiosyncratic criteria to evaluate organizations, even when these organizations are of the same type (e.g., Campbell, 1977; Cameron, 1980; Osborn, Hunt and Jauch, 1980; and Van de Ven and Ferry, 1980). Idiosyncratic causal models suggest that safety, like any effectiveness criteria, is a value judgment about the goals and standards that people use to judge success or failure of an organization or operation. Thus, "it makes little sense to search for 'objective' and universal measures of a concept that is inherently subjective, and is generalizable only to the unique set of decision makers who make value judgments in choosing effectiveness criteria" (Van de Ven and Ferry, 1980, p. 25). Organization theory and logic is a little help in defining a concept that reflects the basic values, or simply the "gut" feelings of people on "what they really want" and "what is important to them." Chapter 5 concerning industry views of safety represents such an approach based on the public pronouncements of industry representatives. As is often the case of industry descriptions, it is very rare to find a discussion of the value judgments and the theoretical rationale used to develop these indicators.

2.2.3 A Practical Approach - Focus on Intermediate Outcomes

It is tempting to fall back on retrospective causal models but there have been too few accidents to confidently identify potentially important management and organization factors on this basis alone. A comprehensive reading of the organizational literature in general, studies of failures in low-probability-high-consequence disasters (such as TMI, Bhopal, Chernobyl and Challenger), and interpretation of the idiosyncratic causal models of managers, suggest that issues of efficiency, compliance, quality, and innovation are important. Therefore, the present research will focus on these four intermediate outcomes. Guiding the choice of the intermediate outcomes are the following assumptions:

(1) Factors that may be able to forecast the avoidance or increased probability of an accident are desired. Ideally, these factors should be removed from actual threats to safety, where

safety is defined as a "decrease (in) the probability that people, property, or environment will be harmed by some event arising from the construction, existence, or operation of a nuclear power plant (Morey and Huey, 1988; page 17.) Thus, we are interested in departures from ideal operations that likely lead to failures.

(2) The underlying probability of failure within the system is assumed to be unknown (see Elster, 1983). There is a probability that an accident will occur under a scenario not currently envisioned. Thus, it is important to identify the general conditions that might induce failure, prevent failure, or add to and lessen the severity of consequences resulting from failure, instead of focusing on precise technological linkages under specific accident scenarios.

(3) The four intermediate outcomes can be logically linked to the operating safety of a nuclear power plant via a reduction in the chances of radiological releases to the environment and the chances of an accident that would yield damage to the reactor core.

2.2.4 Relationship of Intermediate Outcomes to Safety

The following sections define the intermediate outcome variables and attempt to link them to the possibility of core damage and potential radiological releases. (See Chapter 3 for additional operational definitions.)

(1) Efficiency.

Efficiency is a ratio of inputs to outputs (e.g., products per hour of labor), a rate of some desired outcome over time (e.g., output per day), or the amount of an output as a percent of some theoretical maximum (e.g., heat generated/design specifications). Estimates of availability, reliability, critical hours, and the outage rates are some of the efficiency measures used in the nuclear power industry. In continuous process technologies, efficiency can be related to fewer threats which require activating safety systems, less need for human intervention, and greater control over the energy generating process (see Weick, 1988b; Osborn and Jackson, 1988). In essence, with greater efficiency the system is operating more as its designers' intended. There are, however, subtle differences among efficiency measures. When the measure is the ratio of outcomes to inputs it may be difficult to link efficiency to reducing accident risks. Inadequate inputs or doing a particularly good job with marginal inputs is not a good defense against an accident. Greater efficiency might be maintained by reducing defense-in-depth or by sacrificing long-term viability for short-term gain. Chapter 5 describes in detail the indicators proposed by industry. It is obvious from the list and the operational definitions that many of these are efficiency measures.

(2) Compliance

Compliance deals with the degree to which the utility, one of its component units, or a particular employee follows normative prescriptions. These prescriptions apparently vary considerably from nuclear utilities and stem from quite different sources. Most of the "data" regarding nuclear plants' compliance comes from the NRC 766 file. Compliance can be logically linked to radiological releases and core melt to the extent it measures (1) maintenance of defense-in-depth and (2) the utility's willingness to support activities which nuclear experts have linked to minimizing core damage and reducing radiological releases. Some of the compliance, safety, and efficiency measures are related to each other. Scrams, for instance, may be initiated when specific types of non-compliance are evident. However, some efficiency and compliance indicators may not be highly related (see Osborn and Jackson, 1988). In the heavily regulated utility industry there may be conflicts among compliance requirements if compliance measures focus attention on only one particular system, function or issue. Standing alone each may appear reasonable and achievable. Collectively, however, they may call for management to adopt apparently conflicting policies.

(3) Quality

Quality refers to the attainment of excellence. It reflects how the work is actually carried out, or the processes that generate outcomes rather than the outcomes themselves. Quality may focus on (a) technical systems, equipment and components, (b) people, (c) procedures and (d) the interactions among technical aspects, people and administrative systems. It is logically linked to safety in important ways. First, high quality typically connotes that there is additional capacity available to deal with both normal operations and emergency conditions. For instance, during the Browns-Ferry fire non-safety grade pumps were used to help control criticality. If they had been of lesser quality and failed the damage could have been more severe. In a similar manner, operator training is justified on the grounds that operators need in-depth knowledge and experience to successfully cope with unanticipated situations. Second, a focus on quality may reduce emphasis on minimizing costs, short-cutting procedures, and short-term efficiency. While there is considerable speculation on how individuals respond to an emphasis on quality, quality often is considered an integral part of a professional organization (e.g., Mintzberg, 1979; Osborn, Hunt and Jauch, 1980).

Measures of quality vary considerably, ranging from the mundane (e.g., cleanliness of the plant) to those so widely accepted they become a basis for regulation (capacity of feedwater pumps). PRA studies link the quality of technical components to the chances of a specific type of accident. NRC staff judge the quality of a

plant in the SALP reports. Such measures as turnover, absenteeism, morale, and the like might be seen as reflections of quality.

(4) Innovation

Innovation is the development and application of new knowledge. This knowledge may be specific to a particular plant (such as the resolution of outstanding safety issues) or concern the operation of all plants (resolution of a generic safety issue). Measures of innovation reflect three important facts of the nuclear power generating experience. One, knowledge concerning the normal operation of the technology is imperfect. Two, it is not possible to definitively specify all possible accident scenarios and mitigation protocols. Three, nuclear accidents are so infrequent that it is impossible to separate precisely and with statistical support the safe from the less safe. The logical link between innovation and safety is straightforward: the more known about the technology and how it can be managed, the more likely changes can be made to reduce the chances and the consequences of an accident. Both technical and administrative innovation appear to be important for the safety of operating plants. Resolution of technical as well as administrative issues can be linked directly with reducing the chances of an accident and its severity. Unfortunately, systematic estimates of either technical or administrative innovation are comparatively rare (for an exception, see Marcus, 1988a).

While attempts to improve nuclear plants through innovation are generally considered in a favorable light, there are obvious limits on the extent to which innovation should be pursued. As the recent accident at Chernobyl so vividly demonstrated, uncontrolled experimentation can have dire consequences.

2.2.5 Relationships Among Intermediate Outcomes and Between Intermediate Outcomes and Safety Indicators Over Time

Prior work suggests that existing measures of efficiency, compliance, quality and innovation may not be highly correlated (see Osborn and Jackson, 1988, for a review). In part, this is due to measurement problems. In part it reflects the complexity of the nuclear technology itself. The competing values model of organizational effectiveness (e.g., Cameron, 1980), NUREG/CR-3215, and recent analyses of the Challenger accident, suggest that an over emphasis on one of the four safety indicators may yield deterioration in one or more of the others. For instance, we have already noted that utilities might gain in efficiency at the expense of defense-in-depth. Further, less competent utilities, units or managers may use their limited capabilities to perform well on but one dimension if they are not capable of reaching adequate performance on all. And, as noted by Mintzberg (1988) and in NUREG/CR-3215, the administrative systems and management processes needed to maximize efficiency, quality, compliance or

innovation may be quite different. Relationships among the intermediate outcomes may not be symmetrical. It might well be that an unreliable plant will also score lower on compliance, and quality but the very reliable plant may not score well on compliance, quality or innovation (see Osborn and Jackson, 1988).

Linkages among efficiency, compliance, quality and innovation over time and to other desired or undesired future outcomes is far from clear or consistent. Prior success on one aspect of safety may be a poor indicator of future success on another aspect. For instance, high efficiency may reflect comparatively few challenges to engineered safety systems and be used to forecast a continuation of normal operations. With a history of few scrams and interruptions one might argue that the chances of a core melt or a release of radiation to the environment might be smaller than with a history of low efficiency and many interruptions. But following the arguments of Starbuck and Milliken (1988), such may not be the case. With a history of high efficiency one could also argue that (1) operating personnel have less experience with interruptions and thus might be less well equipped to handle an emergency in the future, or (2) maintenance of an outstanding record of efficiency might have come at the expense of experimentation (innovation) or with some sacrifice in the margin of error (reduction in redundancy). On a more positive note, it is quite possible that a number of minor problems with compliance might be used by the utility as a signal for improving safety. Thus, a record of problems might be followed by future successes.

Work by Starbuck and Milliken (1988) suggests that the dynamics among outcomes over time may be influenced by management and organizational factors in quite complex ways. They use the Challenger accident to suggest that repeated success, gradual acclimatization and the differing responsibilities of engineers and managers interact to produce a cycle of fine tuning. Some consequences of changes are unknown. Yet, each engineer and manager attempts to learn from past experiences and improve the system. With conflicting goals, however, some changes yield a reduction in the chances of success and cut the margin of error. In part the dynamics rest on different assumed models relating prior success (failure) to future success (failure).

Three theories relating prior success to future success in low probability high consequence technologies are offered (see Figure 2.2). They are:

1. Prior success (failure) does not change the expected probability of future success. (This is not realistic if one presumes that learning occurs.)

2. Prior success makes subsequent success less likely but failure makes success appear more likely. Prior success fosters complacency, confidence, inattention, routinization and habituation

Figure 2.2

Theories Linking Prior Success to Future Success

Prior Success

1. Does not change probability of future success.
2. Makes subsequent success less likely (complacency).
3. Makes subsequent success more likely.

versus novelty (cf. Weick 1988). Failure motivates engineers and managers to search for new methods.

3. Prior success makes subsequent success more likely while failure yields lower success. Essentially success demonstrates competence while failure shows deficiencies. Yet the very learning mechanisms that flow from success may create organizational conditions that, while increasing efficiency, reduce analysis and slack.

In the events leading to the Challenger accident, the participants' belief in Theory 3 made Theory 2 more realistic. Success bred confidence and fantasy. Conflicting goals and opposing interests also played a role. The interests of managers and engineers are different and they were essentially placed in different organizations where conflict was characterized as external (interorganizational) when in fact it resulted from differences in the goal priorities of managers and engineers. Managers seek cuts in safety because they are wasteful and inefficient (when safety is defined in terms of defense-in-depth). Engineers seek technical improvements. The result is a series of small experiments to improve both efficiency and technical elegance. In a complex social system with multiple goals such experiments may hold unknown tradeoffs and may violate unknown parameters. Experimentation is likely to continue until a disaster occurs.

This link of inquiry suggests that it is important to examine the intermediate outcomes in combination with other organizational predictors. Prior success may predict major problems when utilities have structures that create barriers between managers and engineers.

It is also important to recognize that examining intermediate outcomes in isolation may invert the logic of safe operations. That is, if current measures assess evidence of errors, inefficiencies, lack of compliance, and lack of innovation, and do not attempt to incorporate positive initiatives, then, implied in current measurement is the proposition that the absence of problems connotes a safe operation. Reports by INPO and other industry sources as well as theoretical discussions in the accident literature would run counter to this implied proposition. Active programs for improving efficiency, improvements beyond those embodied in technical specification, and controlled experimentation with new administrative and technological solutions may well be important for future safety. Without measuring efforts to improve, it is extremely difficult to forecast the relationships among the measures over time. Questions regarding the interrelations among specific measures for any one time period and across time periods will be addressed in the discussion of empirical studies in Chapter 4.

2.3 Management and Organizational Predictors

A considerable body of theoretical literature can be used to identify potentially important dimensions of management and organization and to codify specific propositions relating these factors to the four intermediate outcomes of efficiency, compliance, quality and innovation. Several different theoretical perspectives are used in studying management and organization. Scott (1987), for instance, reviews several theoretical schools of thought regarding the linkages among organizational concepts and organizational outcomes. There are numerous schools of thought concerning the linkage between individual/group factors and criteria such as efficiency. A theoretical synthesis of the vast body of literature is not now possible. However, it is reasonable to build upon prior work and suggest a number of potentially important relationships for investigation. NUREG/CR-3215 lists a number of important management and organizational concepts that can be linked to efficiency, compliance, quality and innovation. They are the context of the organization, its environment, organizational governance, and organizational design. These will be discussed and then we will add an additional class of predictors called emergent processes. Figure 2.3 presents the framework. The reader should be aware that this simple representation does not incorporate feedback considerations nor the expected complex interrelationship among the intermediate outcomes and safety as moderated by management and organizational factors (cf Starbuck & Milliken, 1988). The next sections identify the concepts in the framework and list illustrative propositions for future investigation.

2.3.1 Environmental Conditions

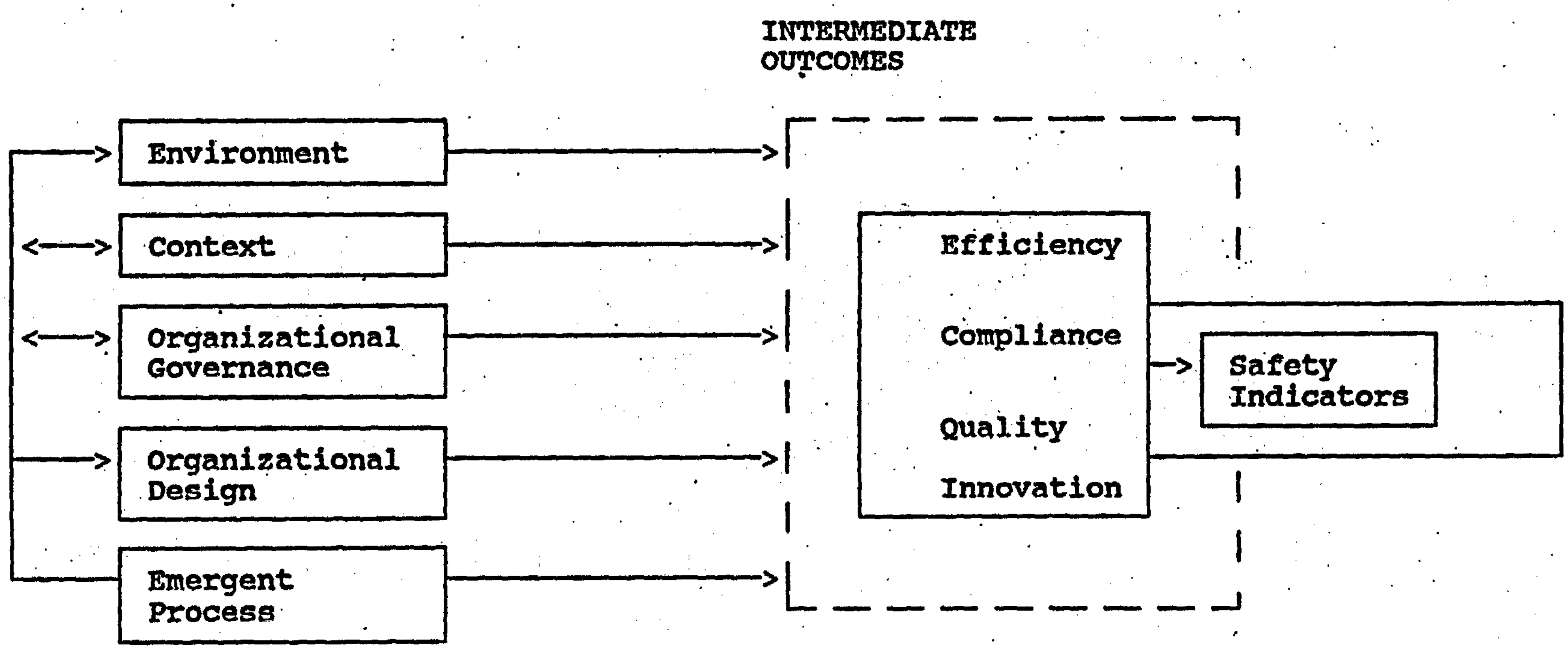
The environment is all factors outside the boundaries of the utility. It has two segments, the general or macro environment and the task environment (also known as the specific environment).

Three factors are to be considered for both segments of the environment: (1) abundance of resources, (2) the amount of volatility and (3) the amount of interdependence within each segment (degree to which change in one area influences other areas). When these three factors are considered together the complexity of the environment may be charted (more abundance, more volatility and higher interdependence signify a more complex environment). Specific propositions about the likely impact of environmental conditions on the intermediate outcomes are listed in Figure 2.4.

Since data regarding the macro environment of utilities may be comparatively easy to obtain, it may be fruitful to more closely examine the influence of the environment on safety indicators. Two avenues might be fruitful. One, measures of external resources may be directly related to the safety indicators. Besides direct

Figure 2.3

Framework for Linking Management and Organizational Factors with Safety



* This model is a slightly revised version of the model found in Osborn et. al. (1983), p. 37.

Figure 2.4

Propositions Regarding Environmental Conditions

P1.1 As greater environmental volatility is coupled with fewer external resources and more dependence upon outside organizations (more complexity), nuclear utilities will find it more difficult to develop an organizational design and governance structure which will promote quality, innovation, compliance, efficiency.

P1.2 The direct or main effect of environmental variables on the intermediate outcomes is:

- more abundance will be associated with higher quality and innovation but lower efficiency
- greater volatility will be associated with lower quality, innovation and compliance
- greater interdependence will be associated with higher quality, lower compliance and higher efficiency

measures of resources, such as return on assets (ROA) and debt to equity ratios, measures of resources might include the rate history of the utility, pressures to return dividends to stakeholders (e.g., dividends to stockholders or lower rates to customers) as well as analyses of power sales by type of customer, and purchases when nuclear reactors are not producing electricity. Two, the analysis could flow from recent theoretical work in population ecology. Particularly important here would be detailed analyses of environmental change over time and the relationships among the type of change and the safety indicators. In both cases recent developments within the literature would need to be extended and adjusted to develop testable hypotheses and an extensive check of existing data sources would be needed to ascertain which hypotheses could be examined.

2.3.2 Contextual Conditions

The context of the organization is defined as size (staff and budget) and two aspects of the technology, technological sophistication and technological variability. Technological sophistication for nuclear plants may be defined in terms of age and megawatts of power that can be generated (plant size), that is, newer larger plants versus older, smaller plants. Technological variability may be seen as plant type and the number of different types of plants, vendors and energy generating technologies (coal, geothermal) used by the utility. This section of the report distinguishes propositions for the nuclear portion of the utility from those relevant to the utility as a whole. Based on the contingency theory literature (e.g. Burns and Stalker, 1961; Woodward 1965; Lawrence and Lorsch, 1967; Van de Ven & Drazin, 1985), propositions regarding contextual conditions are offered in Figure 2.5.

Additional work using available data is quite possible. Inquiry could focus on the potential linkages among technological sophistication, technological variability, and safety. For example, one could explore the relationship of technological sophistication and such specific indicators as equipment breakdowns across the operating cycle to generate plant specific measures of safety risks due to equipment breakdowns. Variations in equipment breakdowns from that expected for the plant could then be used as an adjusted indicator of safety.

2.3.3 Organizational Governance

Organizational governance is the pattern of authority, influence and managerial behavior sought by senior management. Persons in the nuclear industry may refer to this as management philosophy. This chapter provides three "ideal" governance modes. While no one utility is likely to have a governance system exactly like one of the ideal types, they provide a convenient shorthand for

Figure 2.5

Propositions Regarding Organizational Context

P2.1	The larger the nuclear organization, the less it will tend to emphasize quality.
P2.2	The larger the nuclear organization, the more it can take advantage of economies of scale and the greater its potential efficiency.
P2.3	The larger the nuclear organization, the more it can take advantage of economies of scale and the greater its potential efficiency.
P2.3	The larger the nuclear organization, the more it is likely to rely on formal rules to achieve compliance.
P2.4	The larger the nuclear organization, the more likely formal rules will frustrate the innovation process and the more likely specialized staff will have to emerge to take over the function of innovation.
P2.5	The dysfunctional effects of size on intermediate outcomes may be partially offset by changes in organizational governance and design.
P2.6	In very large utilities, or large utilities that operate several new nuclear facilities, a separate nuclear division will emerge.
P2.7	The more sophisticated the technology, the more diverse the organization design and the greater the emphasis on quality.
P2.8	The more sophisticated the technology, the greater the emphasis on innovation.
P2.9	The more sophisticated the technology, the lower the efficiency.
P2.10	The more sophisticated the technology, the weaker the record of compliance.
P2.11	Technological variability will create pressure for a more diverse organizational design.
P2.12	Organizational design and governance choices in response to technological variability will be associated with different levels of quality, innovation, efficiency, and compliance.

discussing a complex multifaceted profile. The three governance modes are:

(1) Traditional - here the chain of command and bureaucracy are valued and the hierarchy is used to prescribe preset processes to be used under specific conditions; the concept of authority is defined by position and rank with centralized authority and comparatively little employee participation. Extensive formal rewards and sanctions are evident and mistakes are often emphasized more than accomplishments.

(2) Modern - also labeled the strong culture model because here the internalization of values is prized over hierarchy as there is often one clearly acceptable, well developed ideology. The purpose of the hierarchy is to maximize compliance with the dominant ideology while the view of authority is based on individual competence, application of the ideology within the organizational setting accompanied by centralized accountability and some emphasis on participation by staff but rarely by lower-level line managers or operators.

(3) Federal - here professional standards are the key constraints placed on individuals and the hierarchy is used to maximize interaction and coordination under the notion that self-interest and professionalism are more effective motivators than coercion as in the traditional mode of governance or normative compliance as in the modern mode. The view of authority is multifaceted and accompanied by extensive decentralization and an emphasis on participation in both defining and solving problems.
Propositions about governance may be found in Figure 2.6.

Obtaining data on management philosophy without the full support of utilities would be very difficult. However, indirect measures of management philosophy and the changes in the senior managers in charge of nuclear plants in recent years suggest that work in this area is important. Two very specific types of analysis might be considered.

One type of analysis involves the risk propensities of senior executive constellations. Osborn and Jackson (1988) argued that the pattern of results in their study of nuclear safety was consistent with "purposeful unintended consequences." They argued that the organizational designs utilities historically adopted for fossil plants were not appropriate for the nuclear technology. Specifically, in regard to management and organizational factors, the nuclear technology was "competence destroying" such that experience with non-nuclear operations at the executive ranks was inappropriate. The inappropriate structures made managing nuclear operations more difficult and more subject to unanticipated consequences. The nuclear executives charged with running the utility had collective biases toward taking risks, with some executive constellations being very risk averse, measured by a

Figure 2.6

Propositions Regarding Governance

P3.1 The traditional form of governance will be associated with higher efficiency and compliance but lower quality.

P3.2 The modern form of governance will be associated with erratic compliance and higher efficiency.

P3.3 The federal form of governance will be associated with higher quality and innovation and lower compliance.

P3.4 The design of the organization will be associated with the form of governance: the traditional will yield more levels of management with elaborate formal controls, fewer coordination mechanisms and much more extensive rules, policies and procedures; the modern will yield centralization, more extensive staff and an emphasis on selecting individuals with a common background such as Navy nuclear or local people from a single university; the federal will yield fewer levels of management, more departments and coordinating mechanisms, decentralization, and the emergence of a quasi-independent nuclear division.

P3.5 Larger utilities and those licensees who are subsidiaries are more likely to have a federal form of governance.

diversified portfolio of generating technologies, and some being technological risk takers as indicated by a heavy commitment to nuclear power.

Second, since TMI, some utilities have started to draw a larger proportion of their employees and managers from the nuclear Navy. Nuclear Navy experience is often considered a plus both for the technical training embodied in the Navy program as well as the emphasis on "quality." However, it is generally recognized that Navy nuclear managers have a difficult transition adjusting to civilian settings where there are different types of authority structures and traditions. The management philosophy embodied in the Navy nuclear program may not be consistent with that needed in civilian nuclear plants. Additional work to examine the changes in management philosophy and transferability of the Navy nuclear experience might be helpful, since it appears that the nuclear industry will continue to rely upon the Navy nuclear program as an important source of experienced managers and employees.

2.3.4 Organizational Design

Organizational design refers to the administrative structure of the organization. Formal structure is the enduring pattern of interactions codified within the organization. Other views of structure emphasize how individuals perceive patterns of authority and command, still others observe interactions to show how individuals repeatedly act. Four aspects of structure can be distinguished: (1) administration or the division of labor, (2) control, (3) coordination, and (4) management and staff development. The division of labor is formally specified in an organization chart and derivable from written procedures; it is also described by participants and may be mandated by external sources such as regulators. The form of administration refers to the division of work into separate units, departments and divisions, plus the position of each of these in the overall vertical and horizontal scheme of the utility. This can often be graphically depicted in an organization chart. Division of labor, control, coordination, and development are envisioned as strategic issues where each utility develops its own unique pattern. For research purposes, it is convenient to use "ideal types" to simplify the development of propositions. In this chapter two ideal types, derived from prior literature are used. The first is labeled "mechanistic" while the second is called "organic". Many organizations will be combinations of these two. Specifically:

<u>Mechanistic organizational designs</u>. In this pattern the division of labor shows many levels of management with narrow tasks for each unit. Functional specialization (e.g., electrical, mechanical, chemical engineering units) is supported by elaborate written rules, policies and procedures detailing the activities for each unit. Control is heavily emphasized with an abundance of written procedures and a de-emphasis on individual discretion.

Coordination (linking of units) is accomplished by means of written protocols, and formal mechanisms are employed to link units (e.g., scheduled meetings following a written agenda are required). Staff development is systematically planned. Formal programs exist for systematically changing the internal operations of work units. the large utility of the 1950's is a prototypical example of the mechanistic organizational pattern.

<u>Organic organizational designs</u>. In this pattern the division of labor shows comparatively few levels of management but more different types of units with more elaborate provisions to coordinate across the organization. Rather than emphasizing written documents, individuals are given considerable discretion. Coordination is stressed over control and an emphasis on individual learning and growth is expected. Individual discretion and external resources such as professional norms are used as substitutes for written documentation. The research university is the prototypical example of an organic pattern.

<u>Diverse organizational designs</u>. In this pattern one finds that part of the organization follows a mechanistic pattern, while another part follows an organic one. A particularly acute problem comes when the mechanistic and organic parts need to be integrated.

Specific propositions are listed in Figure 2.7.

Perhaps no other area more than that of organizational design offers an opportunity to obtain substantial insight and understanding with such minimal effort. After TMI there were several calls for dramatic changes in the organizational designs of nuclear utilities. There were calls for clear lines of authority and responsibility, centralized control of the nuclear technology and clear written specifications for each function with clear functional separation of roles. These recommendations essentially emphasize control. Control is enhanced by clarity, prespecification of responses and an emphasis on engineered systems supported by surveillance of employees and sanctions when action deviates from specifications. Within the plant, these requirements may be seen as logical necessities stemming from the care and extraordinary control necessary to continuously manage criticality and reduce the chances of radiological releases. If all systems, equipment and components (technical, human and administrative) act as designed, the risk of an accident is extremely small. Yet, preliminary data (NUREG/CR-3737) suggested that coordination across functional areas was more important in predicting aspects of safety than strict adherence to maximizing control.

Data regarding organizational design can be obtained from Chapter 13 of the FSAR. However, utilities do not provide updated information for this section nor is the information sufficiently detailed to analyze in a meaningful fashion. NUREG/CR-3737 provided a standardized method for describing the formal

Figure 2.7

Propositions Regarding Design

P4.1 The more organic the organizational design, the higher the quality.

P4.2 The more mechanistic the organizational design, the higher the plant efficiency.

P4.3 The more organic the design of the nuclear organization, the higher the innovation.

P4.4 For routine aspects of the technology, a mechanistic form will be associated with greater compliance, but where measurement is difficult or several alternatives for compliance are available, the more organic design will be associated with higher compliance.

organization of a utility and suggested that it be used to update Chapter 13 descriptions. If this recommendation were followed, NRC and the research community would have information for analyzing the linkage between characteristics of the formal organizational design and safety indicators. With this information three avenues of research could be investigated.

One, with updated data from Chapter 13 submissions, it would be possible to examine the relationships among utility and plant organizational designs and their linkage to the four safety indicators. If, as suggested in the propositions listed above, there are a number of trade-offs, longitudinal analyses of evolving organizational designs over time could be used to chart how utilities adjust to manage paradoxes. Two, it might be fruitful to begin identifying specific elements of the organizational design that are related to specific types of safety deficiencies. That is, it is quite possible that some specific aspects of formal organizational design yield specific safety deficiencies. For instance, in NUREG-3737 the authors noted that an excessive number of vertical ranks was negatively related to some specific measured aspects of safety. The range in the number of ranks was quite large at the time, suggesting that a few utilities were very vertically structured. An overemphasis on the number of ranks itself may not be the problem but it may signal the need to more fully investigate why those with so many vertical ranks selected this unusual profile. Three, with data on the environment and context plus data on the formal organizational design, it would be comparatively easy to examine a number of congruity propositions. These are discussed in section 2.3.6.

2.3.5. Emergent Processes

Since the publication of NUREG/CR-3215, the Bhopal disaster, the accident at Chernobyl and the Challenger explosion, a number of scholars have more systematically investigated the linkages between management and organizational factors and accidents in low occurrence, high consequence technologies. While many scholars discuss environment, context, management philosophy and organization design, they are also concerned with the dynamics that lead or might lead to an accident. Collectively, these analyses suggest that relationships that emerge from the day-to-day operation of technologies are potentially as important as the more general state conditions and management philosophy concerns described earlier. For convenience these management relationships and dynamics are labeled "emergent processes."

Emergent processes are those unplanned continuing dynamics of the organization that allow it to operate with continuity and react to unanticipated conditions. They arise because individuals shape and mold the formal organization, interpret the environment and context, implement management philosophy and generally add variety to that planned into the system. Writers discussing informal

organizations, enactment, leadership, organizational culture and a whole host of informal but important interactions within the organization have contributed to the growing literature on emergent processes.

Appendix A presents three important aspects of this literature: (1) an enactment perspective, (2) institutional perspective, and (3) an organizational learning perspective. Since much of this work is new and quite speculative, the discussion is more theoretical. Chapter 4 presents an empirical analysis based on an organizational learning perspective to illustrate the use of emergent process analysis in the study of nuclear safety.

2.3.6 The Congruity Proposition

NUREG/CR-3215 suggests that intermediate outcome measures may not be highly related with each other and utilities may face quite contradictory pressures emanating from the environment, their size, the nature of the nuclear technology and their historically developed patterns of organizational governance. Specifically, utilities have historically operated in simple and stable environments and attained large size with complicated but not necessarily extremely complex technologies. The traditional form of organizational governance has dominated and all these factors appear to have reinforced a very mechanistic organizational design. Yet, the introduction of a large scale nuclear plant dramatically changes the environment (much more complex), and the context (much larger size, a dramatic jump in sophistication, and additional variety). These changes would suggest that the utility should adopt a different form of governance and a different organizational design.

Yet, the introduction of the nuclear technology placed conflicting pressures on utilities. The greater sophistication was also accompanied by a dramatic increase in the technological hazards -- placing conflicting pressures on the utility's governance and organizational design. Parts of the technology were consistent with the historical pattern since many units within the nuclear area need to be operated with tight controls based on well documented, elaborate written procedures. However, the nuclear generating technology also calls for considerable craftsmanship and professional skill in such areas as operations, engineering and maintenance. To reinforce and encourage such behaviors calls for a supporting organizational design that is more organic and a governance pattern that is closer to the federal form. In different terms, the organization design needed to insure efficiency and compliance is not consistent with that needed for quality and innovation. Utilities faced the need to be both more organic and mechanistic as well as more traditional and more federal.

Data regarding the environment, context, organizational design, and emergent processes could be used to investigate this general congruity notion. It may also be used to test related notions of congruity. Two are outlined below.

One series of questions regarding congruity involves the degree to which specific combinations or profiles among environment, context, organizational design and emergent processes are needed or whether there is considerable opportunity for substitution. For instance, it is possible that as a utility relies upon more different types of generating technologies and operates larger and more sophisticated nuclear plants, it may need a very specific type of formal structure if it is secure and has an above average record on efficiency, compliance, quality and innovation. This suggests a very specific combination with comparatively little opportunity for substitution. It is also possible that there may be several structural combinations that allow utilities with more varied and sophisticated technology to achieve above average scores on the four intermediate outcomes. Statistically, these effects could be isolated in complex interactive equations.

Of course, the congruity analyses are not just limited to those of interactive combinations of environment, context and organizational design. There are important questions of additive effects. That is, pressures from the environment, context and structure may accumulate additively to yield a steady pattern of improvement or deterioration in the four safety indicators. Here, interactions may not statistically contribute to explained variance in any of the outcomes but specific additive combinations involving aspects of the environment, context and organizational design may be important (See Van de Ven, 1985).

As a final point it is instructive to note that existence of multiple goals highlights the importance of trade-offs that organizations may have difficulty making. For example, Perrow (1984), in his discussion of normal accidents notes the functional requirements for both centralization and decentralization to prevent accidents and cope with anomalies when they occur. In his analysis the nuclear technology becomes untenable because he argues that no single administrative structure can simultaneously meet the needs to both minimize the chances of an accident (centralized control) and maximize the potential for mitigation should an anomaly occur (local adaption implying decentralization).[2]

---

[2]Laporte suggests that in risky technologies requiring repeatedly perfect execution of complex tasks (e.g., aircraft carriers), simultaneous formality and informality can be achieved, but it is not specified by senior managers. It may emerge as a mechanism for providing both centralized control and local adaptation.

2.4 Conclusions and Recommendations

In this chapter a framework is developed, grounded in appropriate theory, which directs the thinking of researchers, managers, and regulators to five aspects of management and organization that may be related to four important intermediate outcomes, which in turn should be related to safety. The five aspects of management and organization which are recommended for further operationalization and empirical examination are (1) environmental conditions, specifically abundance of resources, amount of volatility, and interdependence, (2) contextual conditions, especially size, technological sophistication, and technological variability, (3) organizational governance forms, (4) organizational design characteristics, and (5) emergent processes. It is recommended that attention be placed on linking management and organization factors with the four key intermediate outcomes of (1) efficiency, (2) compliance, (3) quality, and (4) innovation, which are argued to be preconditions for safety. A series of propositions are offered and recommended for future empirical examination.

3.0 INTEGRATING NRC RESEARCH, POLICY, AND EXPERT OPINION

3.1 Introduction

The primary objective of this chapter is to integrate NRC research, policy, and expert opinion into a discussion of the relationship between management and organization and safety. Integrating NRC policy, expertise, experience, and knowledge requires combining theory-driven research findings and more inductive and experiential learning. The present chapter incorporates key elements from NRC experience into the theoretical perspective presented in Chapter 2.0 in order to make the theoretical perspective more concrete and practically applicable.

To augment the review of existing NRC publications, interviews were conducted with a small number of key NRC staff and NRC contractors whose responsibilities include evaluating nuclear power plant (NPP) management and organization and developing NPP safety performance indicators. Questions asked included:

- What are the best safety performance indicators for nuclear power plants?
- What are the best indicators of NPP management and organization performance?
- Of all the measures of NPP management and organization, which are most useful to the NRC?

Responses to these questions have been integrated into the discussions below. A summary of the interviews can be found in Appendix B.

This chapter is divided into six subsections including this introduction. Section 3.2 limits the problem focus. Section 3.3 introduces the concept of a causal safety chain. Existing measurement strategies and management policies are evaluated from the perspective of this causal safety chain. Section 3.4 refines the systems goals identified in Chapter 2 (quality, compliance, efficiency, and innovation). Section 3.5 addresses the relationships among conflicting goals. Section 3.6 concludes with a list of propositions about the effect of management and organization on NPP safety.

3.2 Limiting the Focus of Analysis

Chapter 2 presents a theoretical framework for analyzing the relationship between management and organization and safety. This theoretical orientation is capable of generating hypotheses at the industry, utility, plant and even individual worker levels.

Because it is so inclusive, however, a complete explication of a model based on it would be difficult and needlessly complex.

Therefore, two general limits are placed on the framework from Chapter 2. First, the focus here is on operational safety rather than accident management or on worker safety. Second, the focus is at the plant level of analysis.

3.2.1 Focus on Operational Safety

Operational safety refers to the operation of the plant and the conduct of work in such a way that plant conditions do not deteriorate into an accident. Safety is concerned with avoiding transients and assuring that plant safety systems are operable should plant transients occur. This orientation is related but nevertheless distinct from managing accidents and worker occupational safety and health.

A different model of management and organization may be appropriate for the type of uncertainty and rapid decision-making that characterizes accident situations. For example, compliance may play a much smaller role than innovation. While this is a common assumption, it is also untested.

A focus on managing worker safety is excluded at this time in order to establish a parsimonious and practical application of the theoretical approach presented in Chapter 2.

3.2.2 Plant Level

The level of analysis for the proposed model in this chapter is on the nuclear power plant.

The plant level has tended to be the focus of much of the NRC's concern with management and organization effects on safety. While recent analyses have demonstrated that corporate level effects on safety exist (see Osborn and Jackson, 1988; Chapter 2 of this report), the mechanisms identified for these effects work primarily through the plant level (e.g., availability of resources or learning from operating experience). As discussed in Section 3.5, the strategies for managing the paradoxes among the various dimensions of safety performance are enacted primarily at this level.

3.3 A Reconceptualization of Safety

Defining safety for nuclear power plants is not an easy task. Without a clear definition of safety, empirical analyses and regulatory positions on management and organization are not possible or valid. Before beginning the formal discussion of management and organization effects on safety, therefore, it is essential to identify what is meant by safety. A review of recent

NRC literature is helpful in addressing two central questions about the concept of NPP safety:

- What is the nature of the causal chain leading to safety?
- Where in the causal chain should safety be measured for purposes of analysis of management and organization?

3.3.1 Nature of the Causal Chains

The NRC literature and policy on the nature of the causal chains leading to plant safety is a matter of considerable debate. One NRC perspective advocates two primary mechanisms linking programmatic characteristics such as management to safety: the frequency and nature of transient initiators and the reliability of safety systems. As long as safety systems are not challenged, or when challenged they carry out their safety functions, the plant will continue to be "safe." This logic is inherent in the design of the plant reflected in the FSARs and technical specifications. It is also inherent in a recent series of NRC efforts to develop plant safety performance measures which are briefly reviewed below.

The NRC's current position on the nature of the causal chains leading to safety has been summarized in the work of the Interoffice Task Group on Performance Indicators (SECY-86-317). The analysis involved a trial validation of seventeen NPP performance indicators using data from fifty plants at thirty sites for 1984-1986. The dependent variables in the approach consisted of SALP scores and of specific, significant events. The validation approach focused on simple correlational analysis of the seventeen independent variables with the SALP scores. Eight performance indicators were initially recommended for NRC monitoring and evaluating and became the basis for SECY-86-317, "Performance Indicators Policy Statement" of October 1986. The eight indicators selected were based on a plant safety logic model, capacity to predict previous problems, and comparability with the INPO performance indicators. The plant safety logic model adopted stressed the potential roles of transients and safety system unavailability in leading to accidents. The indicators selected either measured directly or were proxy measures of these two plant conditions. The eight performance indicators were: automatic scrams, safety system actuation, significant events, safety system failures, forced outage rate, maintenance backlog, enforcement action index, and mean time between forced outages induced by equipment failures. The selection of indicators is based on the following criteria: availability, non-susceptibility to manipulation, comparability among licensees, independence from each other, and predictability of future NPP performance. Maintenance backlog and the enforcement action index were subsequently dropped. Correlations were estimated separately for different plant categories to assess the effects of age, region, plant type, plant size, and other structural variables. Internal guidance for the

use of performance indicators states that the performance indicator program is to be viewed as providing an additional tool for monitoring trends in operational performance of plants. The performance indicators are to be used as a set only, and in conjunction with other tools. Two continuing research thrusts have been established: the direct, risk-based indicator development, and the indirect, programmatic indicator development.

Work on the direct measures has continued at Brookhaven National Laboratory and has focused on the development and validation of train and system unavailability indicators (Boccio, Vesely, Azarm, Carbonaro, Usher, and Oden, 1988; Vesely and Burlile, 1989). Work-to-date indicates that such indicators can be developed, and that they are logically direct measures of safety and risk of the plant. This lends at least some support to the validity of the logic model underlying the NRC's performance indicators; however the need for additional, risk-based validation is recognized.

AEOD's model of maintenance performance, based on work completed by SAIC and Brookhaven, is divided into two types of indicators: programmatic and process and direct measures of quality or effectiveness (SECY-89-044). From AEOD's perspective, the process indicators have several weaknesses. First, in a limited validation effort, they were found to be only weakly related to plant performance indicators. Second, AEOD found that utilities operationalize the process indicators in many different ways, thus making them unsuitable for comparative purposes. AEOD states that utility management may have a use for process indicators, but they are not useful to the NRC. Some disagree with AEOD's assessment. Because measures are not currently defined and collected in a standardized manner does not mean that they are not ultimately the better ones. Process indicators clearly do pertain to management strategy for maintenance. To assume that they are not useful is to default on what is theoretically the most significant aspect of the maintenance program. The direct measures of maintenance performance are based primarily on data AEOD think are available, particularly NPRDS. Several NRC programs are underway or are recently completed that attempt to develop what are variously referred to as process, indirect, or programmatic indicators for maintenance, management, and other programmatic areas.

Using available data, Battelle (NUREG/CR-5241) tested the relationships between management, maintenance, training, and plant performance. Management was operationalized using generic issues backlog, procedure LERs, and administrative LERs. Training or skill was measured using operator exam scores. Human performance was operationalized using human error LERs for various plant functions. Equipment performance was measured using component failures by plant system. The dependent variable in the model, plant performance, was measured using SALP, scrams, forced outage rate, significant events, forced outage due to component failures, safety failures, and safety system actuation. The analysis found

that the number of issues in backlog and the number of days in backlog are correlated with SALP. The measures were related to several of the direct performance indicators; however, the results were not stable across categories of plant type and age. There was no empirical support for operator exam measures as indicators of training effectiveness. Very little variation among plants was noted for the average exam scores or pass rates. The measures were generally found to have insignificant correlations with SALP, the direct PIs, and the operator error cause code. Equipment performance was clearly related to plant performance. There was no attempt to estimate the full model nor control for environmental and contextual effects. Significant correlations were found between LER cause codes (e.g., operator errors, other personnel errors, procedural errors, administrative control problems) and safety measures by SALP and direct PIs.

SAIC's analyses explore several data issues related to the development of programmatic indicators for monitoring NPP safety. The primary aim of this research is to develop leading indicators of safety based on measures of program safety effectiveness, more specifically, maintenance effectiveness indicators. Wreathal et al. argue that PIs used for regulatory purposes should have the following attributes: (1) reflect a range of plant performance, (2) be independent of each other, (3) represent worthy goals for the utilities, (4) have readily available data to regulatory agency on a timely basis, (5) have data not susceptible to manipulation, (6) be validated for its relation to safety, (7) lead plant performance, and (8) be applicable to all plants. The problem of developing risk-based indicators seems much easier than the programmatic indicators approach, since they are based on events that have been defined through plant performance safety evaluations as challenging plant safety. The analysis argues that programmatic indicators are supposed to measure effectiveness of plant programs to secure safety, but safety is not expressed in a rigorous, quantified and consistent manner.

In the SAIC work, three conceptual frameworks are developed to provide a structured basis for the identification and evaluation of potential performance indicators: (1) a process model, (2) a classification based on the attributes of maintenance having a significant impact on maintenance effectiveness, and (3) a classification of human factors having a significant impact on maintenance effectiveness. Seventy-eight indicators are identified from literature reviews and the process model. Each of these are evaluated for its ability to reflect the attributes and characteristics of maintenance and the frameworks. Based on a reference scheme, a short list of nine potential indicators was developed: (1) number of repeat maintenance items, (2) number of realignment errors, (3) number of wrong unit/wrong train events, (4) number of inadvertent Engineered Safety Features (ESF) actuation, (5) backlog of Engineering Change Notices (ECNs) related to performance, (6) mean time between repairs, (7) scrams due to

test and maintenance, (8) wrong parts events, and (9) gross heat rate. A data validation analysis using systems modeling was completed to investigate the ability of the indicators to anticipate changes in safety performance of the plants that subsequently will affect safety. Four of the nine indicators show potential relationships to measures of safety: (1) gross heat rate (GHR), (2) ESF actuation from test and maintenance, (3) scrams from test and maintenance, and (4) mean time to return to service (MTRS). Further statistical analyses with additional data will be completed by early spring 1989.

The Brookhaven work relies heavily on Mintzberg's The Structure of Organizations for five basic parts of an organization: strategic apex, operating core, middle line, technostructure, and support staff. Five basic organizational structures are identified: simple, machine, professional, divisionalized, and adhocracy. The NPP is described as a machine bureaucracy with some differences in structure within the operating core. Organization characteristics in the model include coordinating mechanisms, design parameters (formalization, functional grouping, vertical centralization), and contingency factors (age, size, regulation). Supervisory/management functions and process include design standards, application, feedback, and override. These are the key processes of the standardization of work. Quantification methods include identification of key personnel, resource allocation, assessment of organizational congruence by means of standardized inventory given to all levels of organization, and observation of supervisors and managers to develop a standardized taxonomy of behaviors. The November, 1988, NRC workshop on organization and management research, organized by Brookhaven, resulted in many suggestions for changes in the Brookhaven model and methods to understand the influence of organizational and management factors on performance reliability. Brookhaven is currently working on those revisions.

In addition to these developmental efforts, the NRC also currently conducts in-depth periodic on-site management and organization evaluations. The implicit model of safety performance in this effort focuses on the following factors:

1. Management and Organization Effectiveness Factors

Goal and Objective Setting
Roles and Responsibilities
Communications
Decision Making
Management Support
Performance Measures and Reporting
Management Information Systems
Policy and Procedures
Planning and Scheduling
Problem Solving

Staffing
Personnel Qualifications
Training and Development
Improvement Programs

2. Organizational Climate

Recognition, Incentives, and Rewards
Working Conditions
Discipline
Attitudes and Morale
Selection and Promotion
Man-Machine Interface

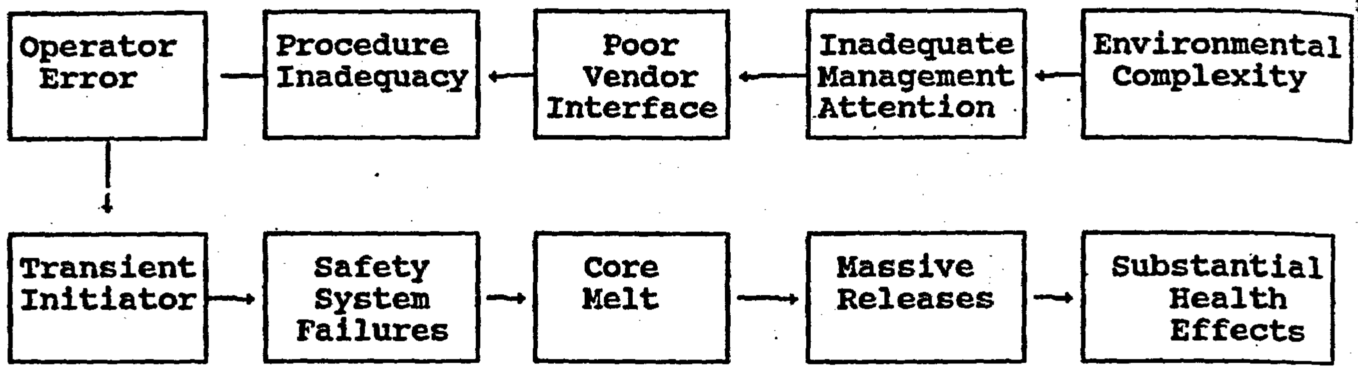
The assumption of this approach is that information about management and organization is related to the safety performance of the nuclear power plants being evaluated. Each of the factors are operationalized through systematic questions on an interview protocol and a data collection instrument. Some questions are directly tied to predefined issues identified by the evaluation team. Examples of these predefined management and organization issues related to the NPPs include problems such as the following: lack of follow-up, control, and tracking of improvement programs, problems in setting priorities and resolving conflicting demands on resources, emphasis on production over safety and quality, and high incident of operating personnel error as a cause of plant performance problems. Each of the factors are systematically linked to predefined issues in each NPP diagnostic evaluation. Questions are developed to probe those issues in depth from respondents at each NPP under review. The approach assumes that the twenty management and organization factors (independent variables) influence NPP safety performance (dependent variable). Safety performance is not explicitly defined in this approach.

3.3.2 Position in the Causal Chain

Some of the disagreement on what constitutes safety is largely semantic and arises from disagreement over where in the causal chain to assess safety, and is based on the different agendas of different interest groups (Chockie et al., 1988; Olson, 1988). For example, the following causal chain reveals how individuals can vary in which phenomena they select to define safety.

The nuclear power industry generally pushes the definition of safety toward the outcome (accident) end of the chain, because on these factors the industry appears to have performed very well, and because this sets limits on regulatory actions, and allows greater plant autonomy. The NRC, on the other hand, has been led by events to be increasingly concerned with the factors further back in the causal chain. It might be said that the NRC is increasingly concerned with safe behavior rather than with safe outcomes. The

pursuit of management indicators is an attempt to move backwards in the causal chain to identify management behaviors and organizational conditions that are predictive of plant safety performance. Because of the serious consequences of a nuclear accident, this orientation is a defensible regulatory position.



Disagreement over what is meant by safety comes not from fundamental disagreement over the nature of the causal chain(s), but rather from economic and regulatory concerns over what part of the causal chain(s) to emphasize.

3.4 <u>Reconceptualizing System Goals</u>

Rather than directly managing safety, the conditions that are necessary for promoting safety are managed. In NUREG/CR-3215 and Chapter 2, these conditions are referred to as intermediate outcomes or system goals--consciously desired "states" that once achieved assure a higher level of safeness (on the average). Logic and the literature have suggested four primary system goals. The primary goals are quality, efficiency, compliance, and innovation.

3.4.1 Additional Refining of the Concepts

General definitions and examples of these concepts have been provided in Chapter 2. A series of refinements are offered to the definitions of the systems goals in order to more clearly identify the nature of the paradoxes, as well as to more clearly represent the logic linking each of the systems goals to safety.

3.4.1.1 Efficiency

Efficiency is generally held to be a ratio of input to output such as thermal efficiency or heat rate, a measure of the ability of the plant to convert the heat generated by the reactor into electrical energy leaving the plant. Heat rate reflects the efficiency of thermal transfer in the steam generator, steam leaks, etc. However, this is not what efficiency means in the context of

safety. Thermal efficiency, in fact, is more directly a measure of quality, conceptualized as technical proficiency.

Efficiency is related to safety because no nuclear power plant possesses an inexhaustible supply of resources; budgets are limited, availability of spare parts is limited; management attention is limited, as are human endurance and the availability of qualified staff. Within the context of deregulation and increasingly conservative PUCs, the adequacy of resources has become even more problematic. The NRC and industry are also concerned with the implications of the "brain drain" away from nuclear power, and the increasing competition for resources brought on by various regulations, INPO programs, and the like. Management's ability to effectively allocate resources is one of the key differences between successful and unsuccessful programs. Several specific examples will illustrate this point.

In its two recent reviews of foreign, domestic, and other related-industry maintenance programs, the NRC has placed great emphasis on the importance of establishing priorities for resource allocation (NUREG-1212; NUREG-1333). A key characteristic of the successful French program, for example, is that clear priorities have been established among maintenance tasks. Components that are most crucial to safety and productivity receive higher levels of preventive and predictive maintenance, and the attention of the most skilled workers during corrective maintenance (NUREG-1333). Alternatively, maintenance programs that are in trouble appear not to have plans and strategies for identifying priority items, scheduling their completion, and assuring quality work. Instead, priority items remain lost in an increasing backlog of work orders, resulting in reduced availability of systems and extended maintenance outages.

Plants and utilities that are efficient in the allocation of resources will be able to provide a broader range of support to operations and maintenance than those plants and utilities that waste resources. Examples include higher fidelity simulators for training operators, greater effort into procedure upgrades, improvements in control room design, greater engineering support in root cause analysis, and in general, more effort in anticipating and resolving problems before they occur.

Finally, management attention as a scarce resource cannot be underestimated. The recent experiences of the TVA and Toledo Edison illustrate this point. Both utilities have been in a position where the tremendous backlog of safety-related problems in design, maintenance, materials, personnel qualifications, and procedure upgrades have created demands on management's administrative and decision-making abilities that have exceeded their capacity. The results have been extended outages, the addition of thousands of personnel to the staffs, and a more hands-on "management" of the programs by the NRC. Solving problems and

learning from experience as means for reducing the daily demands on the organization is a crucial element of safety. Plants that do not solve problems and learn from experience can find themselves exceeding the capacity of management to identify and resolve future safety problems.

The measurement of efficiency is difficult. Potential factors (see Figure 3.1) are the numerous measures of backlog that can be created for the various plant programs, including maintenance work request backlog, design-change backlog, generic issues resolution backlog, and drawing update backlog (NUREG/CR-5241). These measures are not systematically collected by the NRC and suffer from the fact that different plants collect these data in different forms (SECY-86-317), and that items of varying significance are likely to be mixed into a single summary measure.

Efficiency indicators are potentially very powerful discriminators between safe and unsafe plants as they are direct measures of the management functions of administration and decision making, and the availability of resources for pursuing safety-related activities.

3.4.1.2 Compliance as Human Conformance to Standards

As a systems goal, compliance refers to the condition where work behavior conforms to established standards. These standards, in turn, represent the extant knowledge of the organization. In some organizations, knowledge is nearly complete relative to the production process. This has been held to be the case in mass production situations. In other organizations, such as universities, knowledge is constantly being created. However, most organizations seek to increase the conformance of human performance as much as possible. That is, they seek to increase the extent to which performance can be guided by rules and procedures, rather than through the process of discovery or experimentation. Organizations seek to eliminate unknowns, since unknowns are more difficult to manage than are knowns. As new knowledge is created, tested, and accepted, it is typically translated into procedures and standards.

The same is true in the case of the nuclear power plant. Both the utility and the NRC tend to view human performance in terms of compliance to standards, rules and procedures. Much of the research work being conducted by the NRC, as well as many of the activities of NRC inspectors and INPO are designed to make human performance more compliant.

As stated earlier, nuclear power plants are characterized both by knowns and unknowns. Typically, the industry emphasizes the knowns, whereas the industry critics, and some scholars emphasize the unknowns (Perrow, 1983). The NRC tends to adopt a middle ground. FSARs, technical specifications, industry codes and standards, regulatory guides, inspection procedures, and plant

Figure 3.1

The Measurement of Intermediate Outcomes

<u>Efficiency</u>

Backlog Measures

- Maintenance Request
- Design Change
- Generic Issue Resolution
- Drawing Update

<u>Compliance</u>

Events and Procedure Violations due to:

- Inadequate Procedures
- Not Following Procedures
- Inadequate Supervision

<u>Quality</u>

Design/Fabrication LERs
Design Based Generic Safety Issues
Design Based Tech Spec Revisions

<u>Innovation</u>

- Speed of Resolution of Safety Issues
- Frequency of Repeat Failures
- Learning Curves, such as Rate of Decrease of Operational Problems for New Plants

administrative and operating procedures are all used to make the performance of human beings more predictable. When plant personnel begin to deviate from these standards, the NRC frequently issues notices of violations, and in more extreme cases, civil penalties.

The reason for the NRC emphasis on compliance is clear: the standards to which compliance is expected have a causal position in relationship to safety. While it may be argued that the causal relationship for some of the standards is weak, and for a few of the standards, non-existent, the main body of the standards applied to the plant are accepted by the NRC, the industry, and even the industry critics.

Simply having standards, however, does not assure control and compliance. To make human performance tractable, organizations must take steps to reinforce the standards. The first step concerns assuring the quality of the standards. Several reviews of plant operating and maintenance procedures have pointed out that they are frequently incomplete, misleading or difficult to use (NUREG/CR-3698; NUREG/CR-3817). In such situations, performance is not controllable because the guidance is incomplete. The same is true of other "equivalents" of procedures such as supervisory instructions and job performance aids. The ability of the organization to provide good standards and procedures, therefore, should be a predictor of plant safety performance. This ability will be tied to such factors as the allocation of resources within the organization and organizational learning from operating experience.

Assuring compliance against quality standards is, again, a challenge to management and organization. Much of what we mean by management and organization, however, reflects strategies developed to assure compliance. Of particular importance are the following:

- The system of rewards and sanctions available to motivate compliance

- The system of communications available to communicate expectations for performance

- The system of performance monitoring (e.g., supervision, performance trending) available to correct deviations from compliance

Where these systems are "well" developed, human performance is more controllable and compliant and, other things being equal, plants will perform more safely. The difficult part, of course, is defining what "well developed" means.

Performance indicators for the controllability of human performance should reflect both the quality of standards and procedures, and the degree of compliance with them. The available data pertain

most directly to standards and procedures imposed by the NRC, as well as plant procedures by which the utility has agreed to abide. Potential indicators include:

- Number of events (from LERs) and procedure violations (from inspection reports) attributable to inadequate procedures,

- Number of events (from LERs) and procedure violations (from inspection reports) due to not following procedures, and

- Number of events (from LERs) and violations (from inspection reports) due to inadequate supervision.

Interviews with NRC staff revealed other indicators that focus on the issue of compliance, such as:

- Good discipline in the plant
- Face to face management involvement
- Effective systems of accountability, recognitions, and rewards
- Clear policies and procedures
- Good performance standards, performance monitoring, and feedback
- Good job descriptions defining roles and responsibilities

While these variables have not been operationalized, they are consistent with our theoretical orientation. The effects of these factors are reflected in the event and inspection-based measures listed above.

3.4.1.3 Quality as hardware performance

Human performance contributes to excellent performance through its effect on hardware performance. That is, do systems and components fulfill their function when they are called on to do so. When components have been poorly designed, fabricated, operated, or maintained, they are more subject to failure. When components fail, they challenge the integrity of the system function of which they are a part. Therefore, <u>ceteris paribus</u>, when component reliability is high, quality is high, and plant safety performance is high.

Hardware performance is not simply a matter of reliability at the component level. At the system level, and at the systems interaction level, it is a question of design integrity. If the components and systems have not been properly "linked," then even highly reliable components and systems will not assure that the plant performs well. The frequency of these problems can be measured as follows:

- The number of design/fabrication caused LERs per period (year).

- The number of design-based generic safety issues and design-based technical specification revisions applicable to a plant in a given year.

Assumptions about the relationship between reliability and safety permeate the NRC's regulatory philosophy and actions. In general, these assumptions are well founded. Notable examples include:

- The central role given to mechanisms for increasing component reliability (e.g., RCM, preventive and predictive maintenance) in the draft Maintenance Rule.
- Continuing work to develop and validate component and train level failure indicators.
- The use of estimated failure rates as one of the primary classes of "drivers" in probabilistic risk assessment.

Measuring reliability, however, is subject to some difficulty. LER data provide some indication of component failure for safety-related equipment. However, much of the plant equipment, including all balance of plant equipment, is excluded. Another alternative recently considered by AEOD (AEOD, 1988), would use NPRDS data to generate basic reliability measures, primarily because NPRDS is a more inclusive data base. Problems of selective reporting to NPRDS by the utilities remain, however. Neither the LER data base, nor NPRDS is particularly effective in representing degrading performance, as opposed to complete failure of the component. This refinement in the concept of reliability is dependent upon the availability of predictive maintenance data and periodic inspection of components.

To summarize, the concept of quality is directly linked to hardware performance. Hardware performance has a clear relationship to plant safety through the design of the plant, both in terms of transient initiators and the availability of safety systems. However, the integrity of that design and the reliability of components and systems are both necessary to assure adequate hardware performance.

3.4.1.4 Innovation as problem-solving

The central argument is that learning from past experience produces greater problem solving capacity in the present, which in turn supports richer understanding of current problems and their implications and better solutions. If learning is facilitated, that knowledge is carried to the future and leads to safer plants.

Perrow (1983) describes nuclear power plants as an incomplete technology. Specifically, Perrow argues that the complexity of design leads to unanticipated interactions among components, systems, and sources of common mode failure. For Perrow, the

situation is hopeless, and he argues that these unanticipated interactions will eventually lead to major nuclear accidents. For the NRC, however, the incompleteness of the technology is a fact to be managed, within acceptable levels of risk. The NRC does this through identifying generic safety issues, issuing notices and bulletins, and by promoting research in design and operating experience.

From the management and organization perspective, two issues are important: first, has information been made available to allow for problem solving and learning, and second, has a behavioral change in the organization resulted? Both of these issues depend heavily on the nature of management and organization as well as the environment of the utility.

The importance of problem solving for safety is reflected in foreign operating experience. For example, Japanese plants average less than half a scram a year. This high level of performance can be directly tied to an aggressive scram reduction program carried out cooperatively by the Japanese government and the nuclear industry (NUREG-1333). At the hub of this program was the identification of causes of scrams, the dissemination of this information to all utilities, and the implementation of corrective action. Thus, the ability of plants to learn is dependent on the availability of information from the environment.

Simply having access to information from the environment, however, is rarely adequate. A common problem is for information to be poorly diffused once it reaches the organization. For example, TMI-2 had access to information on the PORV problem experienced at Davis Bessie. However, the information was not diffused to maintenance and operating staff, resulting in a near tragedy. Similarly, in an analysis of the effectiveness of NRC notices and bulletins, it was determined that there are numerous organizational barriers to the diffusion of technical information within the organization (NUREG/CR-4991). The ability of the organization to overcome these barriers will have an important effect on safety. These barriers directly diminish problem solving capacity.

Increasing problem solving capacity comes from observing problems as they occur and adjusting practices so that the same problems don't recur. Frequently, first line staff in the various plant functions (e.g., engineering, maintenance, operations) are in the best position to observe problems and, at times, to propose solutions. Thus, the upward flow of communication is an important prerequisite to problem solving.

There are a number of potential measures of problem solving capacity. NRC respondents in interviews recommended:

- A bottoms up approach
- Good two-way communication

- Effective management information system
- Use of performance indicators
- Low number of recurring problems

Quantitative measures that could be constructed out of available data include:

- Speed of resolution of safety issues (see NUREG/CR-5241)

- Frequency of repeat failures (from NPRDS; see also NUREG/CR-5241)

- Learning curves such as rate of decrease of operational problems for new plants

Plants that are able to adopt positive innovations from their environments and learn from their own operating experience should be in a position to improve plant safety performance by minimizing transients, and improving safety system reliability.

3.5 Managing the Four Intermediate Outcomes

Even if relatively clear mechanisms exist for achieving each of the four system or intermediate goals, it is not automatically the case that these mechanisms can be combined in such a way that safety can be maximized. Further, as discussed earlier, it is still not clear that the maximization of each goal, singly or together, is what optimizes safety. In short, as discussed in Chapter 2, the key to managing and organizing for safety may well lie in the ability to manage among the systems goals.

3.5.1 Relationships Among the Intermediate Outcomes

The discussion in Chapter 2 has focused primarily on the paradoxes among the systems goals. That is, the discussion has pointed out that it may be difficult to maximize performance on each of the systems goals, and that therefore safety performance may never be optimal. Several empirical studies have supported this contention by showing that the systems goals are not necessarily positively correlated (NUREG/CR-3215), or correlated in the same way to management and organization (NUREG/CR-3737).

The notion of paradoxes among the systems goals revolves around two key assumptions. The first is that the systems goals are incompatible when viewed as management goals. The second is that management strategies for pursuing the goals are incompatible, either because of their demands on management, or because of their differential implications for employee skill, personality, and motivation.

There is some reason to suspect, however, that these earlier works may have overemphasized the degree to which the systems goals

create conflicts in managing for safety. Particularly given the redefinition of the system goals in this section, there are a number of reasons to expect positive correlations among the systems goals. Further, there are a number of management and organization strategies for managing the paradoxes that remain. A closer look at the relationships among the systems goals is warranted.

If one ignores the problem of managing accident scenarios, hardware performance is most directly tied to plant safety through the logic model that underlies the NRC's view of safety. That is, plant transients (most frequently) and reliability of safety systems are directly affected by the performance of the plant hardware. However, hardware performance is itself affected by and affects the other systems goals. Only at the extremes are these relationships negative.

For example, hardware performance is directly positively related to compliance. Numerous examples exist. When maintenance workers do not follow procedures, inadequate repair is more likely to result than when they do follow procedures. When storeroom personnel do not follow standards for environmental control over spare parts, premature failure is more likely to result. When operators do not follow procedures for tagging out equipment, the removal of multiple trains from service is more likely than when they do follow procedures. While incomplete or invalid procedures may result in damage to the hardware, these situations are the exception rather than the rule. And with proper organizational learning, these situations should become extremely rare.

One of the major questions raised concerning the relationship between quality and compliance, however, hinges on a psychological model of the worker that states, in effect, that workers who are taught to be compliant only perform up to the minimum standards and are not then capable of taking the initiative necessary to deal effectively with non-proceduralized tasks. This dilemma has been present in the organizational literature for many years (Argyris, 1957; Hall, 1968). Looked at from the more general orientation of the tractability of human performance, the dilemma does not appear to be so absolute. For example, the psychologically limiting aspects of procedure based compliance are likely to be more pronounced in situations where workers are already, or are for additional reasons alienated or poorly motivated. Management can attempt to change this situation through the use of the reward structure, or through the promotion of a supportive organizational culture. Leadership can play a key role in the development of an organizational culture that promotes both compliance and excellence. The joint existence of compliance and excellence is the hallmark of the Japanese success story.

The relationship of hardware performance to efficiency is also positive over most of their ranges. The problem occurs when efficiency is emphasized as an intermediate outcome relative to

profitability rather than safety. The discussion in Osborn and Jackson (1988) amply illustrates this. In most cases, there is a long run positive relationship between hardware performance and profitability. Plants that have a lot of equipment failures are plants that are more likely to experience forced outages and extended scheduled outages. They probably also run the risk of increasing the amount of civil penalties and regulatory restrictions imposed by the NRC. The limiting conditions of operations imposed by the plant technical specifications, in fact, make this relationship between hardware performance and profitability essentially positive, even in the short run.

However, there are cases where top utility management may find that short-run profitability is more important than allocating resources to adequately assure hardware performance. It is not uncommon for maintenance departments, for example, to find their requests for special tools, training, and additional staff turned down on budgetary grounds, even if there is some indication that the investment will have near term positive effects on plant availability. Utilities that find that alternative energy sources are more profitable, may actually make the decision to allow plant availability to decline by not investing resources in the maintenance area. As plants near the end of their design lives, the pressures to psychologically and financially "pull out" may also increase. While the factors that might motivate utility management to take this "contrary to safety" perspective are beyond the scope of this section, they will be the primary factors that create a negative relationship between quality and efficiency at the plant level.

However, at the plant level of analysis, the activities of management and organization should indicate a positive relationship between efficiency in resource allocation and hardware performance. Organizational characteristics associated with efficiency include the existence of clear goals, detailed plans and schedules for achieving the goals, well developed mechanisms for monitoring performance relative to the goals, and the assurance of quality input into the goal setting, planning, and monitoring activities. This latter point means that plant level expertise needs to be integrated into management decisions on resource allocation. These same organizational characteristics can be expected to contribute to the quality of hardware performance, by removing the excessive burden on plant personnel that accompanies the lack of planning and scheduling.

Finally, the relationship between hardware performance and learning is particularly significant and positive. Again, a comparison of domestic to foreign experience illustrates this fact. Both France and Japan have substantially lower levels of forced outage time than the average U.S. plant. Both of these countries have very highly developed systems for learning from the operating experience of other plants, and even other countries, and for translating that

knowledge into improved reliability of components and systems. These include management and organizational mechanisms for encouraging upward and lateral communication in the organization. Specific examples are quality circles and job rotation in Japan and, in some respects, the professionalization of maintenance workers in France (NUREG-1333).

The relationship between compliance and resource allocation does not suggest a particularly significant management paradox. At the most abstract level, compliance and budgeting/allocating may seem as very similar, top-down control mechanisms. To the extent that an effective allocation system requires an upward flow of communication, some might argue that compliance and efficiency are negatively related. However, the top-down, procedure-oriented system for assuring the tractability of human performance can be augmented with other organizational mechanisms that allow for both goals to be realized.

The relationship between maximizing compliance and maximizing problem solving capacity is also potentially in conflict. Innovation is typically seen as requiring unfettered creativity that is more characteristic of professionalized jobs than of the types of jobs that require adherence to standards and procedures (NUREG/CR-3215). Organizations that require compliance are not organizations that can freely innovate. This may, in fact, be the case. However, this does not mean that organizations that emphasize tractability are not able to engage in problem solving. Much of the problem solving that is required to improve nuclear power plant safety performance falls far short of what is normally meant by innovation. At the level of incremental problem solving, there is no clear evidence that a motivated workforce cannot evidence both tractability of performance and capacity to problem solve. Management techniques available to increase employee motivation are thus particularly important for resolving whatever paradoxes between problem solving and compliance might exist.

The relationship between efficiency and problem solving, again, is positive, except in the extreme situations where management's attention is not oriented toward improved plant performance. In these situations, there is no compelling need to learn from problems that exist, and to allocate resources to identify and solve the problems.

While conflicts may exist among the systems goals that are prerequisites for safe plant performance, most of the conflicts are not experienced as overwhelming barriers at the plant level. Numerous management and organization tools and strategies are available for resolving the conflicts. Many of the characteristics cited in our interviews of NRC staff, in fact, represent these strategies and tools. Specifically, respondents pointed to the significance of two-way communication, leadership, the development of a culture of safety as characterizing good performers.

3.6 Key Propositions and Conclusions

Figure 3.2 shows a series of propositions which link management and organization characteristics to plant safety through the intermediate outcomes. These propositions reflect considerable agreement between the more inductively generated hypotheses presented in this section, and the more deductively generated hypotheses presented in Chapter 2. Additional work will be required, however, to fully explicate the relationship between management and organization and the system goals. Considerable new data will be required to test the fully developed model. However, the convergence of the different types of information into these propositions suggests that a useful approach to regulating and managing for plant safety is possible.

3.6.1 Conclusions

The testing of the propositions developed in this chapter and in the prior chapter will require more specific operationalization of the measures. Testing also will require the collection of systematic information on management and organization characteristics. However, there is considerable reason to believe that appropriate data collection and subsequent analysis will yield a much fuller and defensible understanding of the relationship between management and organization and safety that can then be used for regulatory applications.

In this chapter then, by limiting the focus to operational safety at the plant level, it has been possible to refine the concept of safety and show the nature of the causal chains linking management and organization to safety. It also has been possible to reconceptionalize the intermediate outcomes, efficiency, compliance, quality, and innovation, and provide operational measures for these outcomes that can be used in future testing. The conflicts between and among these outcomes have been discussed and methods of resolving the conflicts presented.

Figure 3.2

Propositions

Propositions Relating Management and Organization to the Efficiency of Resource Allocation

- The more effective organizational learning, the more efficient is resource allocation, the safer the plant.
- The more effective vertical and horizontal communication, the more efficient is resource allocation, the safer the plant.
- The greater the motivation/morale of the workforce, the more efficient is resource allocation, the safer the plant.
- The more highly coordinated plant functions, the more efficient is resource allocation, the safer the plant.

Propositions Relating Management and Organization to the Conformance of Human Performance

- The greater the efficiency of resource allocation, the more conformance in human performance, the safer the plant.
- The greater the organizational learning, the more conformance in human performance, the safer the plant.
- The more accurate and complete standards and procedures, the more conformance in human performance, the safer the plant.
- The greater the level of supervisory attention, the more tractable is human performance, the safer the plant.
- The closer rewards and sanctions are tied to performance, the more human conformance, the safer the plant.
- The more specific the assignment of responsibility and accountability, the more human conformance, the safer the plant.
- The greater the motivation/morale of the workforce, the more tractable is human performance, the safer the plant.

Propositions Relating Management and Organization to Hardware Performance

- The greater the conformance of human performance, the better the hardware performance, the safer the plant.
- The greater the efficiency of resource allocation, the better the hardware performance, the safer the plant.

Figure 3.2 (continued)

- The greater the organizational learning, the better the hardware performance, the safer the plant.

Propositions Relating Management and Organization to Learning

- The greater the flow of information, the greater the problem solving capacity and learning, the safer the plant.
- The greater the coordination of plant functions and activities, the greater the problem solving capacity and learning, the safer the plant.
- The greater the motivation and morale, the greater the problem solving capacity and learning, the safer the plant.

4.0 AN EMPIRICAL ANALYSIS OF THE MANAGEMENT AND ORGANIZATIONAL ROLE IN NUCLEAR SAFETY

4.1 Introduction

This chapter begins with a brief review of the progress that has occurred in the empirical analysis of the organization and management role in nuclear safety in the post-TMI period. What is meant by empirical analysis is studies that have statistically tested the relationship between management and organization factors and safety measures. A full summary of the studies including a listing of the independent and dependent variables used in the empirical work and the results obtained is provided Appendix C. Also reviewed are a select number of non-empirical pieces. A broader and more comprehensive review of the non-empirical work is found in other chapters in this volume. Following this review of the relevant literature, section 4.2 specifies the dependent variables that are used in the present empirical analysis and sets forth several hypotheses regarding the relationship between them. Section 4.3 describes the independent variables and develops hypotheses which are subsequently tested. Results are reported in Section 4.4, and the conclusions and implications are found at the end of the chapter.

Figure 2.3 in Chapter 2 provides a scheme for organizing the major studies which have been done previously. This figure has been derived from the theory developed in Chapter 2. Figures 4.1-4.5 categorize the existing studies under the headings provided in Figure 2.3. Figure 4.1 starts with the environment of the organization and shows the studies that relate the environment to safety indicators. Fifteen studies have been done. The empirical studies are highlighted in capital letters. Only six of the fifteen studies are empirical. Figure 4.2 shows the studies which relate organization context, governance, and design to safety indicators. Fourteen studies have been done, of which nine are empirical in nature. Figure 4.3 shows the studies which relate emergent processes to safety indicators. Twenty-five studies have been done of which only four have an empirical nature. There are fourteen studies which relate the intermediate outcomes to the safety indicators of which eight have an empirical character (Figure 4.4). The NRC safety indicators, have been analyzed in thirteen studies, of which six are empirical (Figure 4.5).

It is evident from the figures that the empirical work has focused on factors where concepts are easily definable and the data are readily available. For example, studies that relate the organization environment to safety indicators have focused on region and resources (see Figure 4.1) and not on national culture, regulation, dependence on outside constituencies, or the volatility

Figure 4.1

Studies Which Relate the Organization Environment to Safety Indicators*

ENVIRONMENT

National Culture

Thurber (1988)
Boegel et. al. (1985)

Region

OSBORN ET. AL. (1988)
OLSON ET. AL. (1986)
OLSON ET. AL. (1984)

Regulation/Self Regulation

Osborn et. al. (1983)

Ownership and Control

Osborn et. al. (1983)

Dependence on Outside Constituencies

Boegel et. al. (1985)
Osborn et. al. (1983)

Volatility & Interdependence of Environmental Elements

Osborn et. al. (1983)

Resources

Reason (1988)
HENDRICKSON ET. AL. (1988)
OSBORN ET. AL. (1988)
MARCUS (1988)
Osborn et. al. (1983)

*Empirical studies are highlighted in capital letters

Figure 4.2

Studies Which Relate Organization Context, Governance, and Design to Safety Indicators

CONTEXT

<u>Staff Size & Budget</u>

Osborn et. al. (1983)

<u>Technical Sophistication:</u>

Plant Age and Size

OSBORN ET. AL. (1988)
MARCUS (1988)
OLSON ET. AL. (1986)
OLSON ET. AL. (1984)
Osborn et. al. (1983)

<u>Technological Variability:</u>

OSBORN ET. AL. (1988)
OLSON ET. AL. (1988)
OLSON ET. AL. (1986)
OLSON ET. AL. (1984)
Osborn et. al. (1983)

ORGANIZATIONAL GOVERNANCE

<u>Traditional/Modern/Federal</u>

Osborn et. al. (1983)

ORGANIZATIONAL DESIGN

<u>Mechanistic/Organic/Diverse</u>

OLSON ET. AL. (1984)
Osborn et. al. (1983)

*Empirical studies are highlighted in capital letters.

Figure 4.3

Studies Which Relate Emergent Processes to Safety Indicators*

EMERGENT PROCESS

<u>Problem Solving Capacity Organizational Learning</u>	<u>Labor Relations</u>	<u>Cross-Training/Worker Rotation</u>
Weick (1988) Taylor (1985) Bremer (1986)	Bregel et. al. (1985)	Bregel et. al. (1985)
	<u>Supervisory Relations</u>	<u>Worker Attitudes</u>
<u>Organizational Culture</u>	Ryan (1988) Komaki et. al. (1986)	Ryan (1988) Taylor (1985)
Human Synergistics (1987)		
<u>Relations Between Functional Areas</u>	<u>Administrative Problems/ Human Error</u>	<u>Fatigue/Stress</u>
Wreathall et. al. (1988) Brookhaven (1988) Haber et. al. (1988)	OLSON ET. AL. (1988) OLSON ET. AL. (1988) OLSON ET. AL. (1984)	Ryan (1988)
<u>Plant-Headquarter Relations</u>	<u>Training</u>	<u>Additional Items considered by NRC</u>
Wreathall et. al. (1988) Brookhaven (1988) Haver et. al. (1988)	Wreathall et. al. (1988) Ryan (1988) OLSON ET. AL. (1988) Weick (1988) Taylor (1985)	- Goal setting - Decision making - Performance measuring & reporting - Improvement programs - Personnel qualifications

*Empirical studies are highlighted in capital letters.

Figure 4.4

Studies Which Relate Intermediate Outcomes to Safety Indicators*

Intermediate Outcomes

Efficiency

OSBORN ET. AL. (1988)
MARCUS (1988)
Bremer (1986)
Blake (1985)

OLSON ET. AL. (1984)
Osborn et. al. (1983)

Compliance

OSBORN ET. AL. (1988)
MARCUS (1988)
OLSON ET. AL. (1986)
Osborn et. al. (1983)

Quality

Osborn et. al. (1983)

Innovation

MARCUS (1988)

OLSON ET. AL. (1988)

Osborn et. al. (1983)

*Empirical studies are highlighted in capital letters.

Figure 4.5

Studies of Safety Indicators*

Safety Indicators

General

Ryan (1988)
Chockie et. al. (1988)
Popple & Harvey (1986)
Osborn et. al. (1983)

System Assessment of Licensee Performance Indicators

OLSON ET. AL. (1988)
MARCUS (1988)
HENDRICKSON ET. AL. (1988)
INTEROFFICE TASK GROUP (1986)

NRC Performance Indicators

OLSON ET. AL. (1988)
Stello (1986)
INTEROFFICE TASK GROUP (1986)
Pacific Northwest Labs (1985)

Radiation Exposure and Release

OLSON ET. AL. (1986)

*Empirical studies are highlighted in capital letters.

and interdependence of environmental elements. And studies that relate organization context, governance, and design to safety indicators have been concerned with technical sophistication (defined as plant age and size), technological variability (defined as plant type and number of plants per utility), and organizational design (defined as vertical, horizontal, and coordinative structures) and not with staff, budget and organizational governance (see Figure 4.2). Surprisingly, accurate and complete data on staff and budget and on organizational governance (up-to-date organization charts) do not exist, though the data on plant age, size, type, and the number of plants per utility are readily available.

The analysis by Olson et. al. (1984) of organizational design was a difficult and painstaking effort which has not been repeated because up-to-date organization charts are not available. Because of data limitations, they did not attempt to operationalize and measure the mechanistic, organic, and diverse organizational design constructs. The study accomplished the following:

*It examined (1) vertical structure -- the number of ranks and ratio of supervisors to subordinates, (2) horizontal structure -- the division of the organization into work and administrative units, and (3) coordinative structure -- the way the work units are linked.

*It correlated these variables with a dependent safety variable that combines regulatory noncompliance, Licensee Event Reports (LERs), Systematic Assessment of Licensee Performance (SALP) data, and operating data.

*It found that plants with a larger number of vertical ranks, with more departments and a larger ratio of subordinates to supervisors (except in operations), and better developed coordinative mechanisms tended to have better safety records.

These empirical findings are quite interesting, yet they are limited to about two thirds of the operating plants in 1981 and have not been replicated.

Little empirical work has been done in the area of emergent processes mainly because of definitional problems and insufficient data. What work has been done has used the Licensee Event Report (LER) cause codes (see Chapter 3 for additional suggestions as to how to use LER cause codes) to focus on administrative problems and human error, and the operator exam scores to focus on training and other variables (see Figure 4.3). Olson et. al. (1988) found that:

*There are significant correlations between most of the LER cause codes and SALP scores -- personnel error, maintenance problems, design/installation problems, procedure errors, equipment failures

significantly relate to the SALP scores, but operator error and administrative control problems do not.

*There are few significant correlations between 1985 cause codes and 1986 safety indicators such as scrams, significant events, forced outage rate, and safety system failures and actuations. However, there are many correlations between 1986 cause codes and 1986 safety indicators with safety system actuations and forced outage rates being particularly well predicted.

Olson et. al. (1988) also found that:

*No significant correlations exist between pass rates or exam scores and operator error or personnel error. Although operator exam scores correlate significantly with some indicators such as scrams and safety system actuations, the pattern is inconsistent.

The data used by Olson et. al. (1988) in these analyses came from 75 plants.

Emergent processes such as organizational learning and culture have not received this kind of systematic attention. Empirical studies have not been done on the relationships between the functional areas, the relationship between plant and headquarters, the relationship between labor and management, and the relationship between personnel and supervisors. Cross training and worker rotation, worker attitudes, and worker fatigue and stress have not been studied in this manner, nor have the processes of goal setting, decision making, performance measurement and reporting, plant improvement, and personnel qualifications (e.g. nuclear Navy training) received empirical examination.

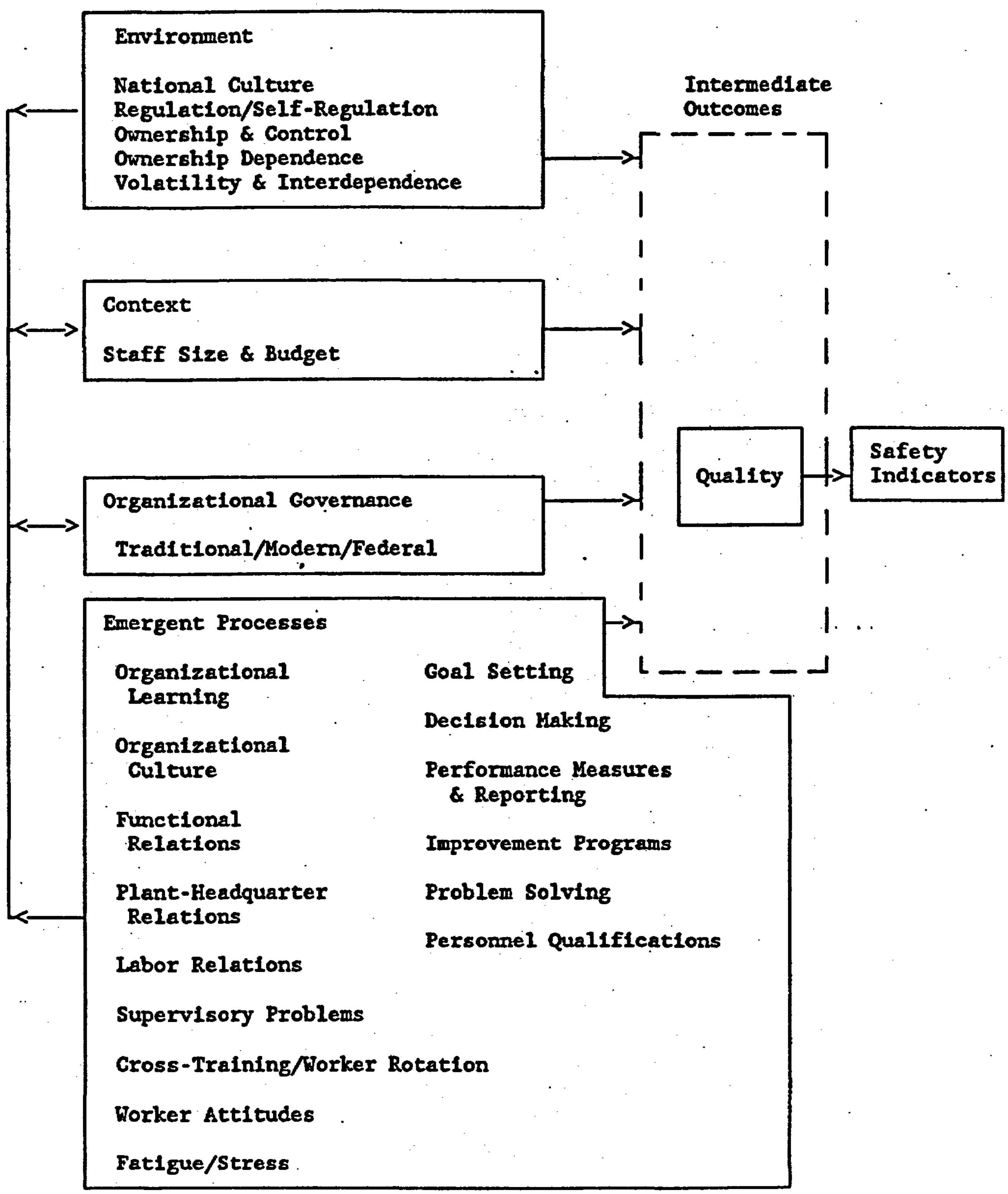
Intermediate outcomes (see Figure 4.4) with the exception of plant quality have received some empirical attention, but here the concepts are easier to define and the data are more readily available. NRC also has devoted resources and attention to the development of safety indicators (see Figure 4.5).

A list of some of the factors which have <u>not</u> received empirical attention is found in Figure 4.6. No centrally organized scheme has guided the efforts of the NRC or the scattered researchers who have done the existing empirical research. Ryan (1988) therefore criticizes the existing studies for failing to provide "logic models as opposed to mere individual indicators and measures of performance."

To overcome this shortcoming the present research takes a first step toward using the logic model developed in Chapter 2 to determine what can be learned with the available data. By understanding what the existing data reveal, NRC will be in a better position to undertake additional empirical research. In this chapter attempts are made to be as systematic and

Figure 4.6

Factors That Have Not Been Empirically Examined



comprehensive as possible by incorporating into the analysis as many factors and as many plants and years as possible. As Figure 4.7 shows, the focus is on a set of environmental and contextual factors and the effect of an emergent process, namely organizational learning, on efficiency and safety. Sections 4.2 and 4.3 justify the selection of the variables, explain how they are related, and how in combination they are hypothesized to affect safety. More will be said about how organizational learning has been defined and why it is considered important later in the chapter.

First it is important to note how safety has been conceptualized. NRC has made progress in defining and operationalizing safety, and this chapter builds on that progress. In NRC's charter safety is defined as the requirement to protect the public health, prevent accidents, and in case of accidents to minimize the consequences. Ultimate and final indications of lack of safety would be serious accidents, significant overexposure, and massive releases of radioactivity. So-called penultimate safety measures are concerned with conditions that would dramatically increase the likelihood of direct safety effects -- substantial degradation of plant safety systems or excessive challenges to these systems, and exposures or releases that approach or exceed regulatory limits. Osborn et. al. (1983) operationalized safety by relying on a factor analysis consisting of Licensee Event Reports (LERs), forced outages, violations, and Systematic Assessment of Licensee Performance (SALP) data. Olson et. al. (1984) used this operationalization in their early empirical research. In October 1986, based on the work done by the Interoffice Task Group (1986), NRC selected a group of safety indicators that had such desirable features as non-susceptibility to manipulation and comparability between licensees. These indicators include automatic scrams while critical, the total number of significant events, forced outage rate, safety system actuations, and safety system failures. They have been used in recent empirical research (e.g. see Olson et. al., 1988). The logic model NRC used in developing these indicators is presented in Figure 4.8. As can be seen NRC is concerned with low frequency of transients, high availability of safety systems, inherent design features, and low potential for cognitive errors.

The efforts described in this report are intended to assist NRC in determining indirect indicators that relate to these safety outcomes. Two sets of hypotheses have been developed. The first set relates efficiency measures and safety indicators to one another (see section 4.2). A second set of hypotheses relates the environmental, contextual, and process variables to the efficiency and safety measures (see section 4.3).

Figure 4.7

Factors Examined in Initial Empirical Analysis

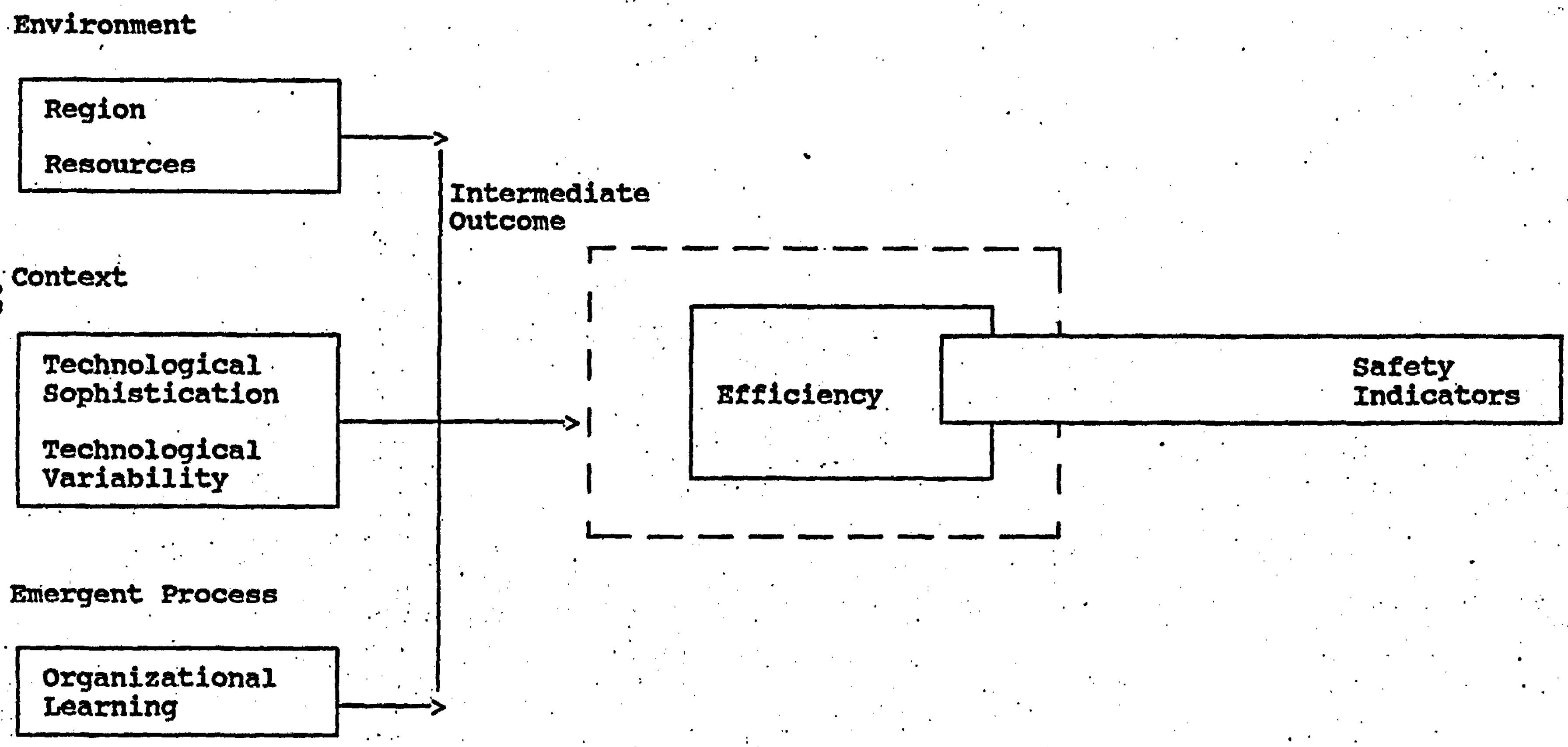
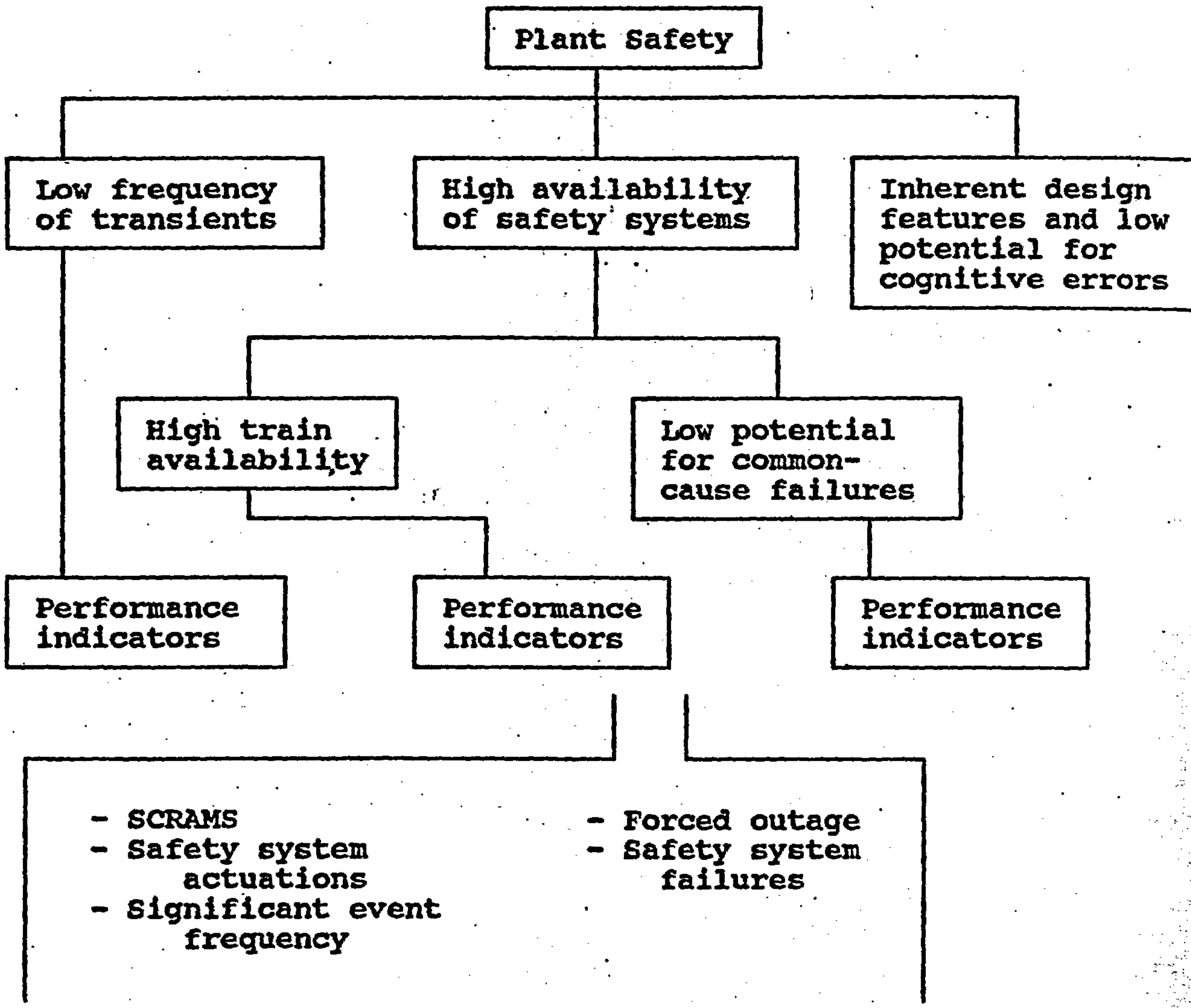


Figure 4.8

NRC's Performance Indicators: Logic Model*



* Adapted from Interoffice Task Group (1986), secy 87-31.

4.2 The Relationship Between Safety and Efficiency

Organizational goals such as safety and efficiency serve many purposes in organizations. They are both motivating devices and evaluative devices. On the one hand, "they provide orientation by depicting a future state of affairs which the organization strives to realize , "and on the other hand, they constitute the "source of legitimacy which justifies the activities of the organization, and, indeed, its very existence (Etzioni, 1964; p. 5)."

Analysts have trouble agreeing what the appropriate goals for an organization should be. Price (1968), Steers (1975; 1977), Campbell (1977) and Cameron and Whetten (1981) have assembled lengthy lists of criteria that have been used in assessing organizational effectiveness (Scott, 1987). Campbell (1977), for example, lists thirty different goals from productivity and profits to growth, turnover, stability, and cohesion. Cameron and Quinn (1988) propose a framework which evaluates organizations from a variety of perspectives which are assumed to conflict with or contradict each other.

It is clear that many organizations have more than one goal. They are multipurpose in nature --an example would be a university that serves both a research and a teaching purpose. Thus, the management of goal conflict, that is, the ability to strike a balance between the demands of competing goals or evaluative criteria is an important aspect of management that has great significance for both the viability and success of an organization (see chapters 2 and 3 for additional discussion).

Five different organizational forms, each with its own distinctive orientation, are supposed to exist (Mintzberg, 1979). For our purposes, three of these organizational forms and the values they represent are important. The "machine bureaucracy" tightly controls work by means of explicit rules and standards. The "professional form" delivers complex but essentially standardized services by granting professionals considerable autonomy and discretion to apply their skills. This form relies on professional training and collegial relations to get the job done. The "innovative form" melds experts into multi-disciplinary project teams (adhocracies, matrix organizations) to create novel, complex outputs. According to Mintzberg (1988), the machine bureaucracy emphasizes efficiency, the professional form proficiency, and the innovative form learning. In a recent paper (1988) he raises the possibility that there are hybrid structures or anomalies -- "those nasty, well functioning organizations that refuse to fit" into one of these categories. With regard to hybrids, some type of balance among goals is needed:

> ...truly successful configurations do not exist in pure form...other forces...may be secondary, but their presence is necessary to contain the dominant one.

> Otherwise the organization risks running out of control...the balance is lost without the other forces to anchor it...Each configuration...contains the seeds of its own destruction residing in its own dominant force. Too much technocratic control destroys the machine organization, unimpeded leadership destroys the entrepreneurial one, and so on. But held in check by the other forces, each configuration can be very effective (Mintzberg, 1988; p. 9).

An example of an effective hybrid is IBM which, according to Mintzberg (1988), is both highly efficient and very innovative.

What about nuclear power plants? Mintzberg's (1988) discussion suggests that they too are hybrids. The emphasis on the design and execution of standards makes them both professional and machine-like in nature, which means that the dominant values and goals will be some combination of proficiency and efficiency. However, nuclear power plants also have to deal with unexpected problems and ensure their correction. In this regard they are innovative in nature and their orientation is learning. Here is Mintzberg's description (the underlines are ours):

> ...with their plethora of controls and standards, these plants looked primarily like <u>machine</u> organizations...But on re-examination, we found more going on...the design of the facility and its construction required another form of organization, <u>professional or innovative</u> depending on how established was the technology at the time of construction. And the design of the standards...an ongoing activity that involved great numbers of engineers in their technostructures looked rather professional in nature. (Indeed, there was so much of this going on that plants could almost be characterized as professional organizations in the business of writing standards!) It was the execution of the design, the day-to-day operations and maintenance of the facility, that looked machine-like, because compliance to the standards was so critical. But further consideration suggested that these systems had a need for <u>learning</u> too, that the operators occasionally had to cope with unexpected problems in the short term and to ensure their correction in the long term by communicating their presence back to the engineers. This seemed to require an innovative layer on the machine structure. <u>And finally, the managers of all this had to deal with the contradiction between machine-like compliance on the one hand and innovative learning on the other</u> (pp.12-13).

Mintzberg's (1988) view is that no goal is entirely dominant and it is up to the managers to deal with the contradictions and to manage the paradox (see Poole and Van de Ven, 1988). This is a

problem, a major difficulty, for according to Mintzberg (1988), such combination of contradictory elements "is not the preferred way of organizing." It is "effective only so long as the organization has no choice" (also see Porter, 1980; and Child, 1975 and 1977, for arguments that organizations require a consistent focus or set of goals to be successful).

Mintzberg (1988) is not alone in the finding that the management of nuclear power plants consists of dealing with goal conflict and paradox. For Perrow (1984; p. 10), the conflict involves the competing goals of autonomy versus centralized control or direction:

> ...because normal accidents stem from the mysterious interaction of failures, those closest to the system, the operators, have to be able to take independent and sometimes quite creative action. But because these systems are so tightly coupled, control of operators must be centralized because there is little time to check everything out and be aware of what another part of the system is doing. An operator can't just do her own thing; tight coupling means tightly prescribed steps and invariant sequences that cannot be changed.

Perrow (1984) believes that systems cannot be both decentralized and centralized at the same time and for this reason nuclear power plants are untenable as management systems. In a 1983 article, he appears to favor autonomy over central direction. He maintains that efforts to centralize authority reduce the role of operators to passive monitoring. When the operators no longer have significant decisions to make, they lose proficiency which increases the chances of error. These efforts at centralization encourage low system comprehension, low morale, and an inability to cope with anything but the most routine conditions. According to Perrow (1983), autonomy is needed to encourage a higher level of commitment and a greater level of knowledge. On the other hand, Weick (1987; p. 122-123), while he highlights the importance of autonomy, recognizes that a balance between autonomy and rules is necessary to achieve reliability in high risk technologies.

Many of the propositions developed in Chapter 2 highlight the role of goal conflict in the management of nuclear power plants; for example, more resources will lead to higher quality and innovation but lower efficiency; the "traditional form of governance" will be associated with higher efficiency and compliance but lower quality; and the "federal form" will be associated with higher quality and innovation but less compliance. A basic insight is that the organizational design which is needed to insure efficiency and compliance is not consistent with that needed for quality and innovation. Chapter 3 also has a discussion of goal conflict and how through leadership and motivation this conflict can be overcome.

While there are many conflicts and potential paradoxes in managing nuclear power plants, in this chapter the focus will be on the safety/efficiency trade-off to which Pate alludes in the quotation which comes from the next chapter (letter to NRC, September 16, 1985):

> Focusing on a narrow set or one indicator can be counterproductive to safety. For example, overstressing the achievement of a high capacity factor for the short term, or seeking to set records for continuous service, could cause plant management and operational personnel to make non-conservative decisions with respect to safety.

The efficiency measures used in the present research are critical hours and outage rate. The safety indicators are scrams, significant events, the forced outage rate, safety system actuations, and safety system failures. The hypothesized relationships among the variables are as follows:

<u>Hypothesis 4.1</u>: Efficiency measures will be significantly and positively correlated with each other.

<u>Hypothesis 4.2</u>: Safety indicators will be significantly and positively correlated with each other.

<u>Hypothesis 4.3</u>: The efficiency measures will not be significantly and positively correlated with the safety indicators.

<u>Hypothesis 4.4</u>: The efficiency measures will not be significantly negatively correlated with the safety indicators.

<u>Hypothesis 4.5</u>: The efficiency and safety measures will be significantly and positively correlated with the NRC's ratings of the plants (the Systematic Assessment of Licensee Performance or SALP ratings).

Hypotheses 4.1, 4.2, and 4.3 intend to establish that safety and efficiency are separate performance dimensions. Safety indicators should correlate with safety indicators and efficiency measures should correlate with efficiency measures. If safety indicators correlate more with the efficiency measures than with the other safety indicators, then safety and efficiency may not be empirically distinct measures. Hypothesis 4.4 is designed to establish the limits to which safety and efficiency work at cross-purposes: they are not significantly negatively correlated. Safety is not achieved at the expense of efficiency, nor is efficiency achieved at the expense of safety. This point is important, for if safety and efficiency were significantly negatively correlated

solutions to problems at nuclear power plants would be "zero-sum" in nature. Safety would have to be achieved at the expense of efficiency, and efficiency would have to be achieved at the expense of safety. There would be less room for maneuvering and less hope of mitigating or at least managing the demands of the two conflicting requirements. The hypothesized relationships are displayed in Table 4.1.

In an interesting article on managing goal conflict, Simon (1977) presents the dilemma in the following light. Ideally, when two opposing goals exist in an organization one would like to optimize on them both. However, when it is not possible to do so, a single goal will rise to a superior position becoming the basis for <u>choosing an alternative</u> and another goal (or goals) falls to subordinate status becoming the basis for <u>testing the alternative</u>. The first goal is a goal in the "true sense," and the second (or third, fourth, and fifth) becomes what Simon calls the "constraint." For regulators, managing and operating nuclear power plants safely may be the "true goal" with efficiency falling to the status of constraint, but for utility managers efficiency is more likely to be the main goal with safety occupying the status of a critical constraint. Note that in a sense this distinction is purely formal. Simon (1977) argues that both goals and constraints play important roles in decision making. The situation with regard to divergent goals, A & B, can be imagined as follows:

1) A and B both can be maximized.

2) A can be achieved with B being the critical constraint.

3) B can be achieved with A being the critical constraint.

4) A can be achieved only at the expense of B.

5) B can be achieved only at the expense of A.

Reconciling divergent priorities is much easier under conditions 1 - 3. When efficiency and safety measures are significantly negatively correlated, as is the case under conditions 4 & 5, then managing nuclear power plants is a more challenging proposition.

Van de Ven and Poole (1988), Simon (1977), and Cyert and March (1963), offer additional perspectives on how organizations can reconcile divergent goals and manage conflict. According to these authors, organizations can:

1) ignore the conflict between goals;

2) localize the conflict in separate units or entities; and

Table 4.1 Hypothesized Relationships Between Efficiency Measures and Safety[1]

	Efficiency Measures	Safety Indicators	SALP Ratings
Efficiency Measures	+	0	+
Safety Indicators	0	+	+

+ indicates hypothesized positive relationship
0 indicates no hypothesized relationship

[1]Efficiency measures are critical hours and outage rate

3) pay sequential attention to goals, letting time be their main ally.

Solution 1 is made possible by solutions 2 and 3. Less attention may be paid to conflict if it is localized and if managers are able to use time as an ally. Under these conditions, pressure is applied but at different times and in different directions. Resiliency is maintained because the pressure never comes from the same direction simultaneously.

With respect to localizing conflict, what happens is that "different constraints define the decision problems of different positions or specialized units (Simon, 1977; p. 260)." For example, nuclear power plants are divided into different units -- production units which are more concerned with efficiency and quality assurance and safety review units which are more concerned with safety (see Marcus and Osborn, 1984). This system of dividing responsibility among units works, so long as there are "weak rules of consistency" (Cyert and March, 1963; p. 118); that is, so long as a series of independent decisions reached by separate decision centers can be harmonized without the need for central direction. As long as the process of the "hidden hand" is at work harmonizing opposing tendencies, the conflict among these tendencies is not likely to put undo strains on the organization. When conflict is localized, different forms (Mintzberg, 1988) dominate different parts of the organization; for example, a bank runs a "machine-like" retailing service where the focus is on efficiency while at the same time it has a "more innovative" wholesaling service which emphasizes learning. Within the same organization, different organizational styles or cultures co-exist: production departments with clear goals and short time horizons function according to the bureaucratic mode, while marketing and research and development departments have different goals and develop different means of organizing (Lawrence and Lorsch, 1967).

This idea of parceling the organization into different units with different purposes is in accord with contingency theory which holds that there is no "one best way" of organizing. The appropriate organizational form depends on the task and the environment in which the unit finds itself, and management must be concerned with achieving a "good fit." Some of the classic contingency theory studies have shown the following:

> Machine bureaucracies are appropriate for only some technologies, for firms using mass-production technologies, but not for firms using unit, small batch, or process systems of production where flexibility and organizational learning are important (Woodward,1965).

> When market and technological conditions are turbulent and uncertain, a greater degree of organizational differentiation and less integration are required (Lawrence and Lorsch, 1967).
>
> When changing technological and market conditions pose new problems and challenges so that success hinges upon constant improvements in product, production process, or design, then open and flexible styles of organization and management are likely to perform better than organization and management that is based on the machine analogy (see Burns and Stalker, 1961).

Mintzberg and his colleagues Miller and Friesen (1978) and (1984) have attempted to confirm the central insights of contingency theory that:

(1) machine bureaucracies are appropriate for simple tasks carried out in stable environments;

(2) the professional bureaucracy is best suited for complex tasks in stable environments where trained people can be given the freedom to do successful work; and

(3) the innovative form works best in unstable environments where flexibility and informality are at a premium.

According to Drazin and Van de Ven (1985), the organizational implications of different contingencies

> are unlikely to be the same and are often in conflict with each other. As a result, trade-off decisions begin to emerge, and attempts to respond to multiple and conflicting contingencies are likely to create internal inconsistencies in the structural patterns of organizations (e.g. see Drazin and Van de Ven, 1985; p. 521).

An analysis of the safety review groups created at nuclear power plants after the TMI accident found that the strategy of parceling the organization into different units with different purposes does not always work (Marcus and Osborn, 1984). At some nuclear power plants, members of safety review groups perceived many problems and made numerous recommendations for change, but the nuclear power staff responsible for production considered the recommendations irrelevant because they interfered with the tasks of production. The correction of error depends not only on the recognition of previous inadequacies. It also requires that someone have enough power to take action (Marcus, 1988).

A basic premise is that nuclear power managers have to balance at least two major outcomes, safety and efficiency, that doing so is not easy, and that how this conflict is managed is critical to effective nuclear power management. Each of the independent

variables in the model to be tested is likely to affect these outcomes. How they are likely to do so will be discussed in the next section.

4.3 The Factors Affecting Safety and Efficiency

For the purpose of this discussion the independent variables are divided into two categories: (i) variables that do not change or that change slowly and predictably over time -- region, relative plant age and size, and number of plants per utility; and (ii) variables that change in a less certain and predictable manner - major violation and Licensee Event Report (LER) data and information about profits and debt. Signals about plant safety, that is major violation and LER data, interact with signals about financial performance to either facilitate or inhibit organizational learning; that is, these signals affect both the recognition of problems and the adoption of new practices to mitigate these problems. Organizational learning is a function of recognizing problems and having the resources to correct perceived deficiencies.

Explication of the concept of organizational learning will emerge as the independent variables and how they are likely to affect safety and efficiency is explored. The discussion will proceed in the form of a series of hypotheses about the relationships between independent and dependent variables. A summary of the hypothesized relationships is found in Table 4.2.

The first hypothesis is that:

> Hypothesis #4.6: Some of the independent variables will have a significant effect on both the efficiency measures and the safety indicators, but the direction of this effect is uncertain.
>
> > 4.6.a: Region will have a significant effect on both the efficiency measures and the safety indicators but the direction of this effect is uncertain.
> >
> > 4.6.b: Reactor supplier will have a significant effect on both the efficiency measures and the safety indicators but the direction of this effect is uncertain.

Region may be an important factor reflecting different NRC inspection and enforcement policies. It may also capture different local cultures as well as the availability of skilled labor and the degree of unionization. An important aspect of local culture that may have some bearing on both safety and efficiency is support for

Table 4.2 Summary of the Hypothesized Relationships Between Environmental, Contextual, and Process Variables and Efficiency and Safety Measures

	Efficiency[1] Measures	Safety indicators
Region	NH	NH
Reactor Supplier	NH	NH
Number of Plants Per Utility	+	-
Plant Age	+	+
Plant Size	-	-
Major Violations	-	+
Recent LERs	-	-
Earlier LERs	+	+
Recent Financial Resources	-	-
Earlier Financial Resources	+	+

+ indicates hypothesized positive relationship
- indicates hypothesized negative relationship
NH indicates no hypothesized relationships

[1]Efficiency measures are critical hours and outage rates.

nuclear power. The success of the French program, for example, may be related to the high degree of support for nuclear power that exists in French society. Of the four major regions in the United States, more nuclear power plants are located in the South (about 35 percent), with fewer plants found in the West (about 13 percent) and a roughly similar proportion (26 percent) found in the North and Midwest. Because region represents different things, interpreting regional effects is difficult. At a minimum, region is an important control variable in the analysis. Region will have a significant impact on the safety and efficiency of nuclear power plants but the direction of this effect is uncertain.

Reactor supplier determines the type of technology that is used: all General Electric plants are boiling water reactors (BWRs), while all Westinghouse, Babcock and Wilcox, and Combustion and Engineering are pressurized water reactors (PWRs). There may be features of one design that lead to typical problems that affect plant performance; for example, the safety systems of General Electric plants may be less reliable than the safety systems of the other suppliers. About 43 percent of all United States operating reactors are Westinghouse; 34 percent are General Electric; 14 percent are Combustion Engineering; and 9 percent are Babcock and Wilcox. Most Combustion Engineering reactors are found in the West. The Westinghouse design was used in the first development of nuclear submarines. Westinghouse and General Electric are the companies that first designed and sold reactors for commercial energy production. That more utilities have chosen Westinghouse and General Electric to supply their reactors may indicate that they believe that these suppliers are better. That Westinghouse and General Electric have supplied a majority of reactors may have given them the experience to perfect the technology; they may be further along the "learning curve" than the other reactor suppliers. It was, after all, a Babcock and Wilcox reactor which was involved in the TMI accident. It would be logical to expect that the Westinghouse and General Electric supplied reactors will have better performance records. Indeed, the existing empirical evidence tends to support this proposition, particularly in regard to the superiority of the Westinghouse supplied reactors (e.g. see the chapter by McLaughlin in Osborn, et. al., 1983; Olson et. al., 1986; and Olson et. al., 1988).

The next hypothesis is that:

> Hypothesis #4.7: Some of the independent variables will have a significant positive effect on the efficiency measures, but a significant negative effect on the safety indicators (see Figure 4.9).
>
> > 4.7.a: The number of plants per utility will have a significant positive effect on the efficiency measures, but a significant negative effect on the safety indicators.

Figure 4.9

Hypothesized Effect of Number of Plants on the Efficiency Measures and Safety Indicators

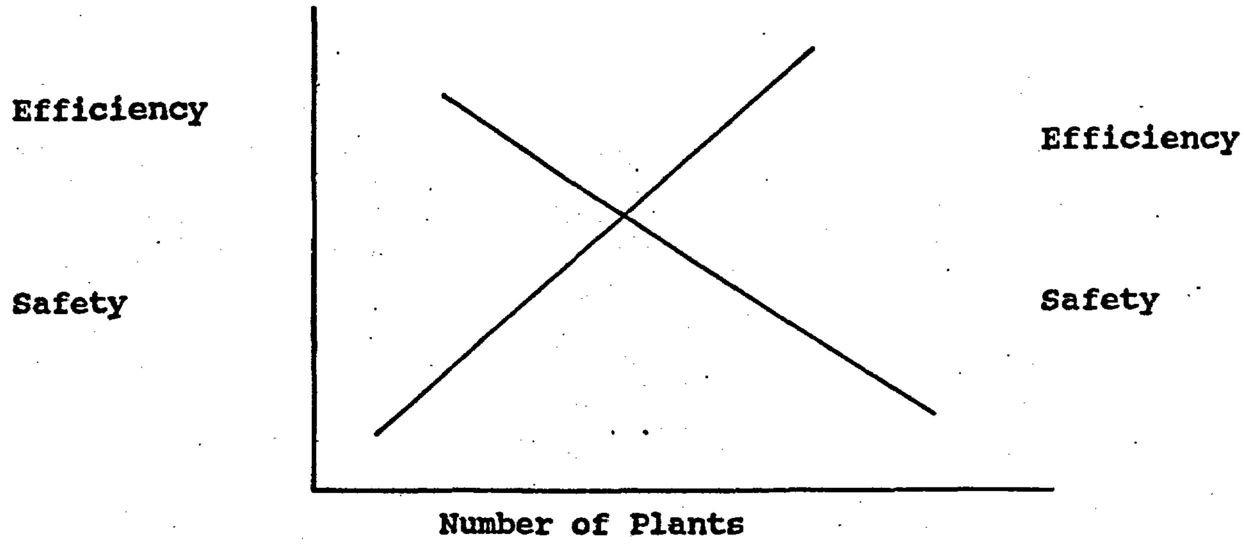
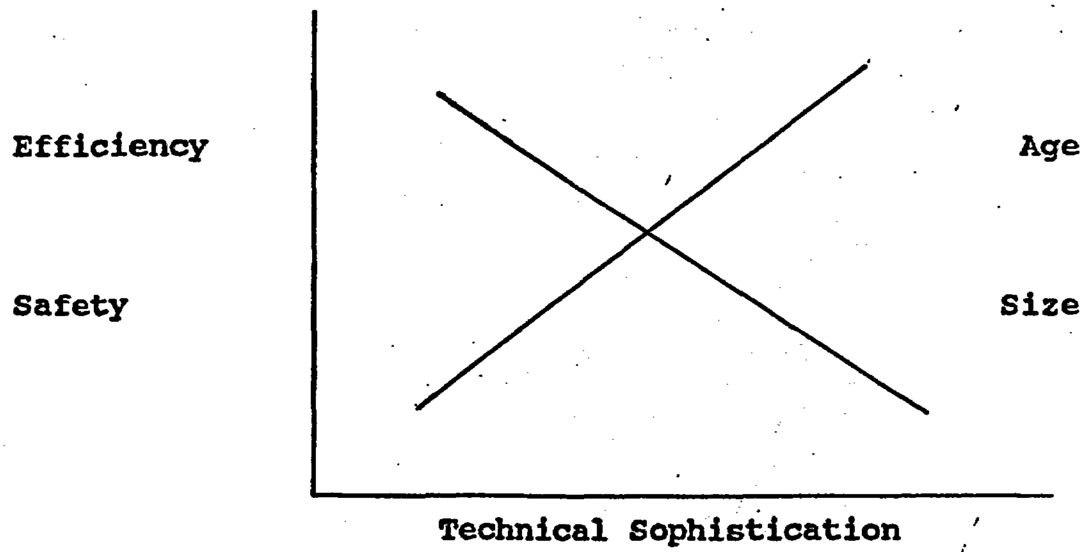


Figure 4.10

Hypothesized Effect of Technical Sophistication (Age, Size) on Efficiency Measures and Safety Indicators



In their empirical work, Osborn and Jackson (1988) find a substantial positive correlation between the number of plants a utility has, the number of major violations, and plant reliability, as measured by the ratio of total operating hours to total hours the plant could have operated had it not experienced a forced shutdown. Essentially what they find is that the more nuclear power plants a utility has the more efficient, but the less safe it is likely to be. They interpret their finding to mean that prior success and investment in nuclear-generating technology influences the risk propensities of executives and may lead them to gamble with public safety to increase profits. Executives engage in this type of behavior, which they call "riverboat gambling," as a result of "purposeful unintended consequences" arising from "ignorance" and "self-serving myths" that inhibit access to the information needed to reduce the ignorance.

There is another way to interpret the Osborn and Jackson (1988) findings. Rather than focusing on the propensities of executives, it is possible to attribute the relationship between the number of plants and their performance to organizational and bureaucratic imperatives. Brookhaven National Laboratory (1988) has developed a descriptive model of a nuclear power plant that uses the machine metaphor (for a discussion of organizational metaphors see Morgan, 1986). Basically, this model means that management consists of designing standards which govern behavior, applying these standards, obtaining feedback, and, when called for, overriding the standards. This metaphor suggests that it is the orderly relations among the clearly defined parts that allows for routinized, efficient, stable, reliable, and predictable operations. Such attributes as efficiency and reliability are achieved through the fixed division of tasks, hierarchical supervision, and detailed rules and requirements (see Weber, 1947). According to this model, managers have two major responsibilities:

1. The organization of the work. It is up to them to use "scientific methods" to determine the most efficient way to carry out the tasks (see Taylor, 1911). They may organize tasks in the minutest detail. The "thinking" is done by the managers, while the "doing" is left to the employees.

2. Planning, organizing, commanding, coordinating, and controlling production. Managers then select, train, and monitor employees to ensure that procedures are followed and appropriate results achieved (see e.g. Fayol, 1949).

The machine metaphor is most appropriate when there are straightforward tasks to perform and the environment is relatively stable (Morgan, 1986).

However, machine bureaucracies have a major flaw -- an inability to adapt to changing circumstances, to learn, and to innovate. Flexibility and the capacity for creative action are not attributes

of this type of organization. In industries such as aerospace and microelectronics, where such qualities are needed, a machine bureaucracy may be a severe liability. A machine-like structure tends to reinforce past behaviors, whereas a more flexible structure tends to allow for shifts in beliefs and actions and for learning (see Fiol and Lyles, 1985). When a utility has many plants, bureaucratic rigidity and lack of flexibility may set in, and these factors may affect the ability of the utility to safely manage its plants. With fewer plants, organizations are likely to be more creative and flexible. They may have a greater capacity for problem solving which motivates them to achieve a higher level of safety. Rather than the characteristics of leaders, the relationship between number of plants and performance may be a result of these differences in flexibility and ability to solve problems.

The next hypothesis is that:

> Hypothesis #4.8: Some of the independent variables will have a significant positive effect and some a significant negative effect on both the efficiency measures and the safety indicators (see Figure 4.10).
>
> 4.8.a: Age will have a significant positive effect on both the efficiency measures and the safety indicators.
>
> 4.8.b: Size will have a significant negative effect on both the efficiency measures and the safety indicators.

With age comes experience. In manufacturing, simple production experience is supposed to create the capabilities that prompt improvements or progress (Dutton et. al., 1984). Classic studies done in manufacturing industries have shown that efficiency increases continuously due to a growing stock of embedded knowledge about production. As knowledge accumulates about the physical equipment and the materials used in production, the skills of the producers tends to increase. Many of the initial studies of the learning curve in manufacturing were carried out in the American aviation industry where unit costs declined rapidly with cumulative output. Other industries were then studied. The hypothesis was that the phenomenon might be widespread, that the learning curve parameter might approach being a universal constant. Post-War empirical studies in numerous industries, however, showed considerable variation between processes, products, firms, and facilities. Each basic process in the manufacture of a product has its own basic progress function without there being stable progress rates or universal progress functions (Yelle, 1979).

It has been suggested that the same simple process that applies to efficiency might apply to safety (Greenberg, 1970). With regard to

nuclear power, there is considerable evidence that experience as defined by age is related to safety (McLaughlin, undated; Olson et. al., 1986; and Olson et. al. 1988) . Older plants tend to have fewer LERs and major violations. However, it is likely that the relationship between experience and nuclear power plant performance is not a simple one. In the startup phase and early stages of production, many problems may occur. This period of instability may be followed by a relatively trouble-free stage, but as nuclear power plants begin to reach the end of their useful life maintenance and equipment obsolescence problems surface and proliferate. The problems of youth and old age may both manifest themselves in a poor performance record.

<u>Size</u> introduces another complication into the argument. Average net MWe of generating capacity decreases with age. Most new nuclear power plants are larger, and larger reactors built recently have had more operating problems. Although designed to achieve greater economies of scales, they have frustrated their designers' intentions as they have been off-line and plagued with safety problems to a greater extent than anticipated. The performance problems of the large reactor has prompted some analysts (see Eschbach and Schuller, 1983) to call for a return to a smaller, simpler reactor. Size and age, however, may be masking a third factor that has nothing to do with the inherent capabilities of the technology. Wildavsky (1988) has blamed the performance problems of the large reactor on regulation. According to Wildavsky, newer, larger reactors have been subject not only to more regulation but to more attention from regulatory officials, all of which has had a negative effect on their performance. Osborn et. al. (1983) combine age and size and refer to this variable as technological sophistication. Technological sophistication may capture some of the concern that Wildavsky (1988) has expressed about increased regulation. With greater sophistication, i.e. size and newness, comes increased regulation. In any case, the past empirical evidence about the impact of age and size on performance suggests a considerable effect (e.g. see the chapter by McLaughlin in Osborn, et. al., 1983; Olson et. al., 1986; and Olson et. al., 1988). Therefore, technological sophistication is important in the framework being tested.

4.3.1 <u>Organizational Learning</u>

Another set of factors that affect safety and efficiency are related to organizational learning. Organizational learning is an emergent process variable. It consists of two sub-processes - problem recognition and taking remedial action. The variables used to operationalize problem recognition are the number of major violations and LERs. To operationalize the capacity to take action, financial indicators are used. Before being more specific about our hypotheses, we need to further develop the concept of organizational learning.

The need for knowledge in organizations that manage and run high risk technologies is very high. For example, when first introduced, bridges, natural gas lines, and commercial air travel all appeared to be dangerous. Today, these innovations are accepted and commonplace. By recognizing and dealing with the problems in these systems, the number and severity of incidents have been reduced and society is better able to live with the consequences of the residual danger (see Wildavsky, 1988). To the extent that the members of high risk organizations develop useful knowledge about the problems they confront, these organizations will be more effective. Useful knowledge in this context is knowledge about action-outcome relations (Duncan and Weiss, 1979); it is knowledge of the relationship between the organization's actions and various safety outcomes. The organization starts with certain core beliefs about these action-outcome relations. It has an existing knowledge-base, a paradigm, a way of seeing or organizing the principles governing perception, that is embodied in the organization's pre-operational plans and carried out during the early stages of production. If all goes as expected, the pre-production paradigm will not change. However, it is unlikely that the initial knowledge base is perfect. Problems occur and members of the organization realize that there are discrepancies between the organization's performance and the expectations that have been formed about how it should be performing (Downs, 1967).

Typically, learning begins when ambiguous and ill-defined problems arise--perhaps some type of crisis temporarily occurs, a small shock or jolt that disrupts existing routines. This crisis may cause existing standards to be reinterpreted according to a different frame of reference or different cognitive schemes. Problem recognition then leads to a search for alternative courses of action, through the generation of new understandings that will reduce the performance gap. If organizations are to learn, they must have this capacity to sense, monitor, and detect significant deviations in operating experience (Ashby, 1960; Wiener, 1961). They also must be able to relate this information to the operating norms that guide their behavior and initiate corrective action when discrepancies are detected.

It is the recognition that there is a mismatch between outcomes and expectations that leads members of the organization to try to discover the source of problems. They may attribute the difficulties to strategies and assumptions in their existing "theory-in-use" and investigate alternative ways to understand their situation (Argyris and Schon, 1978). However, if learning is to take place it cannot be to correct actions only in accord with existing operating norms and procedures. When these norms and procedures are not appropriate, organizations have to have sufficient capability to question them. Learning theorists, therefore, have distinguished between (1) detecting and correcting deviations <u>from</u> pre-determined norms in order to <u>maintain</u> a course of action established by the existing norms and (2) detecting and

correcting errors in the existing norms so as to create new norms to guide subsequent behavior (see Argyris and Schon, 1978). At nuclear power plants this distinction is supposed to apply to the different roles of quality assurance and safety engineering, with quality assurance groups maintaining compliance with existing norms, while safety engineering groups are supposed to be able to challenge these norms.

The classic strategy for learning, then, is trial and error in nature: establish a policy, observe the effects, determine what the problems are, correct the problems, observe the effects, and correct again. Evidence for the use of this strategy comes from both the Japanese and French nuclear power programs. The Japanese refer to this process of recognizing and correcting problems as "crytallization" (Matsuda, 1984). The French philosophy (Bremer, 1986) is even more explicit. They build less expensive plants risking some failures during the first five years of production with the aim of correcting the weak points after start-up rather than before. Trial and error learning is a device for courting small dangers to avoid the damage from big ones (Wildavsky, 1988). So long as errors are small, recognizable, and reversible, it may make sense to solve the problems associated with high risk technologies as they surface. But are the errors experienced by high risk technologies small, recognizable, and reversible? When catastrophic potential is imminent and interactive complexity and tight coupling are present, Perrow (1984) believes that learning from events such as chemical plant explosions or nuclear power plant accidents is neither tolerable nor possible:

> In the past, designers could learn from the collapse of a medieval cathedral under construction, or the explosion of boilers or steamboats, or the collision of railroad trains on a single track. But we seem to be unable to learn from chemical plant explosions or nuclear plant accidents (p.12).

Perrow (1984) believes that learning about the operation of high-risk technologies quickly reaches a "plateau," that the learning curve is likely to be flat. Wildavsky (1988), however, vigorously disputes that conducting trials that involve error is too risky and that the only alternative is trial without error.

4.3.2 Barriers to Learning

Whether one agrees with the views of Perrow (1984) or Wildavsky (1988), it is necessary to recognize that the barriers to learning may be substantial. Consider the following (see Steiner and Steiner, 1988). In 1981, three years prior to the Bhopal tragedy in India, a phosgene gas leak at the Bhopal plant killed one worker. A crusading Indian journalist wrote a series of articles about the plant and its potential dangers. In 1982, when a second

phosgene leak caused temporary evacuation of the surrounding slums, Union Carbide engineers from the United States conducted a survey of the plant. They found approximately 50 safety defects but all of them were accorded the status of minor and Carbide management stated that there was no imminent danger. The events that occurred prior to the tragedy at Bhopal are not unique. Another example comes from Three Mile Island (TMI). A failure to learn lessons from previous incidents was one of the factors that contributed to operator confusion at TMI (Kemeny, 1979). The implications of a similar incident at the Davis-Bessie plant in Toledo, Ohio were analyzed by the NRC and a nuclear power engineer at another nuclear power station, but the implications were not properly communicated to the personnel at TMI. One can examine almost all recent disasters and find that warnings were given but not heeded. Appropriate adjustments were not made and learning did not take place. The phenomenon of the technical specialists who discovered O-Ring problems prior to the Challenger disaster is a common one. The fact is that problems that lead to major tragedies may not be appropriately recognized. It is hard to distinguish the true "signal" from "noise" and as a consequence appropriate corrective actions may not be taken (another example comes from the crash of the Pan Am jetliner over Scotland). A recent NRC report (Thurber, et. al., 1988) shows that the problem of assimilating information about precursor events and incidents still exists in the nuclear power industry. Licensees must cope with vast quantities of information, some redundant and most of varying importance and usefulness. If either the internal or external environment is too complex and dynamic for the organization to handle, an overload may occur, and learning may not take place (Fiol and Lyles, 1985). Too much change and turbulence make it difficult to learn.

March and Olsen (1976) maintain that in understanding the barriers to learning the usual assumptions are that policy makers not only know the difference between success and failure but that they also know what is happening and understand why. These authors question the perspective which emphasizes that it is simply organizational rigidities that prevent the implementation of known solutions to well-defined problems. Policy-makers, according to March and Olsen (1976) often do not know what happened or understand why:

> ...organizations adapt their behavior in terms of their experience, but that experience requires interpretation. They learn under conditions in which...what happened is unclear, and in which the causality of events is difficult to untangle. People in organizations come to believe what happened, why it happened, and whether it was good; but the process by which those beliefs are established in the face of a quite problematic "objective" world affects systematically what is learned (pp. 55-56).

The character of the underlying state of the world, of decision-makers' ability to perceive that state, and of the authority and control systems in the organizations for which individuals work all influence how problems are identified and if action is ultimately taken (Marcus and Fox, 1988).

Psychologists (Fischoff et. al., 1981) have shown that when confronted with uncertainty about the underlying state of the world, human beings are prone to make fundamental mistakes. For example, humans tend to consider themselves personally immune to hazards which other individuals would readily acknowledge. They have difficulty imagining events of low probability with severe consequences involving themselves. They tend to underestimate the error and unreliability which are inherent in small samples of data. They judge the probability or frequency of events on the basis of the ease with which they can retrieve information about similar events from memory, and rely on the saliency and the recentness of events in their evaluations. Direct experience or exposure biases judgment. No matter what the implications of further evidence, these starting points or "anchors" affect judgment. There is also a tendency to believe that past performance will be a valid indicator of future occurrences.

Individual judgment under conditions of imperfect knowledge about the state of the world has its limitations, but so too does collective judgment. There may develop in groups working on problems of risk an illusion of invulnerability and the suppression of doubts (Janis, 1982). Such attitudes are affected by the consensus within the group, the insulation of the group from external criticism, and the active promotion of the views of a dominant individual to the exclusion of the views of others. On the other hand, shared information in groups can lead to greater realism in the perception of problems (see Vinokur, 1971). New information and rationally persuasive arguments can be introduced into discussions within a group and better use can be made of existing information. The critical factor may be the way the group's decisions are framed (Whyte, 1989). If framed as a choice between two or more unattractive options, the consequences are likely to be increased risk taking. Thus, group discussions influence judgment, depending on such factors as the size of the group, its composition and values, and how these affect the framing of issues.

Organizational objectives, capacities, and interests also have an effect on problem recognition. Decision-makers usually confront many sources of information which compete for their attention. This information varies in its completeness, pertinence, and reliability. To understand and to use the information is difficult because it cannot be readily aggregated or organized according to clear principles and it cannot be recalled without error (Hammond and Mumpower, 1983). Critical information, therefore, might be ignored or suppressed and only congenial information recalled and

emphasized. While the establishment of special units for detecting problems (Landau, 1973) might be useful, a potential drawback is that the special units separate their members from the problems confronted at the front-line. Such relationships can breed resentment and uncooperativeness.

The literature on the barriers to learning suggests that it is difficult for people in organizations to appropriately recognize problems. A good understanding of how people at nuclear power plants recognize potential problems and learn from them would require detailed case studies which is beyond the scope of the present phase of this project. In evaluating whether problems exist and corrective action is needed, nuclear power plant managers are likely to look at many sources of information, including procedural deviations, personnel errors, non-conformance reports, quality assurance audits, operating experience reviews, operating event reports, NRC violations, and licensee event reports (LERs). For purposes of the present research, the sources on problem recognition which are used are the (i) major violation and (ii) licensee event report data. Violations can be initiated after a variety of regular and non-routine NRC inspections, inquiries, and investigations. Each violation begins with the statement "contrary to" and the specific guide or standard which is violated is then cited. The violation is then categorized as major or minor. It is recorded according to regular rules which guarantee a fair degree of consistency over time. Bias in the violations data may occur if regional offices and inspectors have varying standards and perceptions of compliance. In the present empirical analyses this potential bias has been controlled for by taking region into account.

The other source of data used as a surrogate for problem recognition is the LER data. In compliance with a plant's technical specifications, utilities are required to send information to the NRC about events that may have potential safety significance. There are two types of events that have to be reported--those requiring 24-hour notice and 14-day follow-up versus those requiring a 30-day written report only. About 20 percent of all LERs are of the more serious 24-hour notice variety. Unlike the violations data, LERs are generated by the utilities and may be biased to some degree by how the utilities report the events. For example, there may be a tendency on the part of some utilities to report more events and a tendency on the part of others to report fewer events. Technical specifications and licensee provisions also vary among nuclear power plants and may cause some reporting differences. Analyses of the causes of LERs can be generated from the Sequence Coding and Search System maintained by Oak Ridge National Laboratory. These cause codes have been used by Olson et. al. in their 1988 analysis. Unfortunately, the Olson et. al. (1988) cause code data begins in 1984 and the full 1980 to 1985 LER data is needed to carry out the present analysis. The reason for this will be explained shortly.

Violations data get at what Rasmussen et.al (1987) call "rule-based behavior," that is, behavior controlled by a stored rule or procedure which may have been derived empirically during previous occasions and communicated from other person's know how as instruction. The relationship between rule-based behavior and actual safety is uncertain. Marcus (1988a), for example, warns of the possible consequences of passive acceptance of external dictates by those who strictly follow the "letter of the law;" they may be doing so in "bad faith" and may not achieve the results intended. Major violations, though, are a relatively rare occurrence. The average nuclear power plant has only about one per year.

We hypothesize that:

> Hypothesis 4.9: Some of the independent variables will have a significant negative effect on the efficiency measures, but a significant positive effect on the safety indicators (see Figure 4.11).
>
> > 4.9.a: The number of major violations a utility has will have a significant negative effect on the efficiency measures, but a significant positive effect on the safety indicators.

When a major violation occurs it is likely to reflect a serious situation that needs to be taken care of immediately. It may cause the plant to reduce production for a period of time so that managers can assess the situation, determine what has gone wrong, and make the appropriate adjustments. Thus, in the period immediately after a major violation, safety will improve but only at the expense of efficiency. The plant is safer because it is not operating at full capacity. In an empirical analysis, Adler and Clark (1987) document a similar phenomenon based on the idea that advances in learning typically are by production setbacks. In the short run, learning detracts from a plant's efficiency. For example, when a plant makes a model or design change, production proceeds on an intermittent basis as the design or policy change occasions changes in other areas yielding temporary "losses in learning" and the need for "re-learning" when production starts again on a full-scale basis.

In accord with the theory of Cyert and March (1963) organizations are subject to short feedback loops. They solve each problem as it arises. They then wait for another problem to appear. Major violations claim the first attention of nuclear power plant managers. The effects of LERs on organizational learning are more complex. Here we return to the idea of sequential attention to goals that was raised in the last section. The hypothesis is that:

Figure 4.11

Hypothesized Effect of Number of Major Violations on Efficiency Measures and Safety Indicators

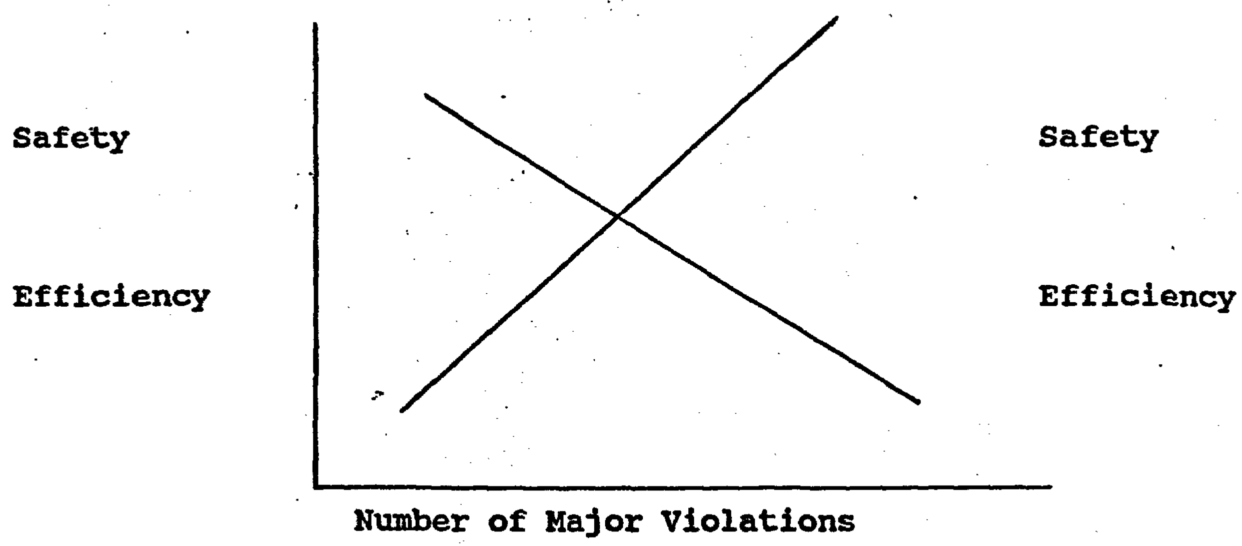
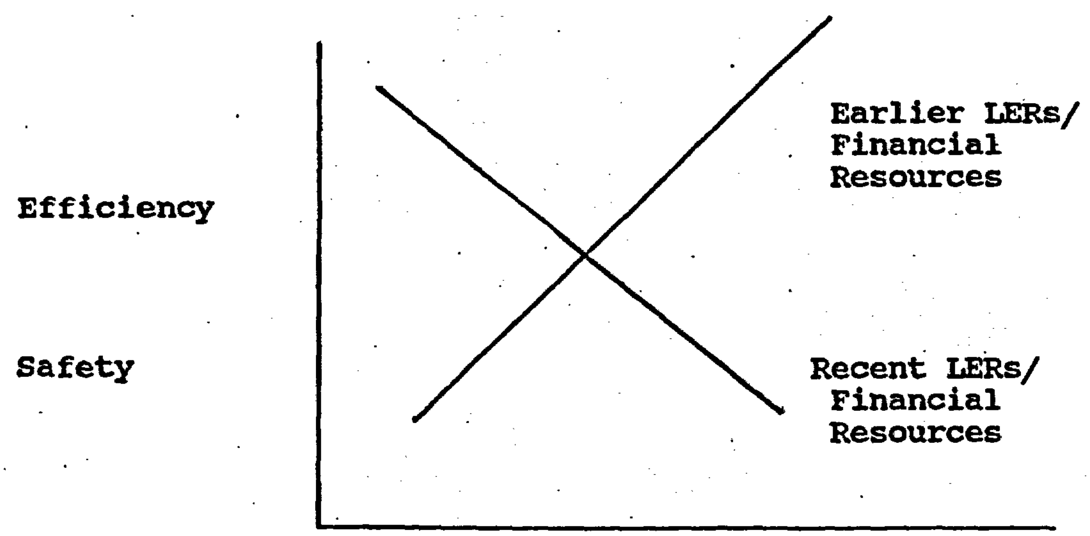


Figure 4.12

Hypothesized Effect of Licensee Event Reports (LERs) and Financial Resources on the Efficiency Measures and Safety Indicators



Hypothesis #4.10: The effect of some of the independent variables depends on when they occur (see Figure 4.12).

4.10.a: Recent LERs will have a significant negative effect on both the efficiency measures and the safety indicators.

4.10.b: Earlier LERs will have a significant positive effect on both the efficiency measures and the safety indicators.

4.10.c: Recent financial resources (return on assets and financial leverage) will have a significant negative effect on both the efficiency measures and the safety indicators.

4.10.d: Earlier financial resources (return on assets and financial leverage) will have a significant positive effect on both the efficiency measures and the safety indicators.

Unlike major violations, which are a relatively rare occurrence, LERs are common. Even after the NRC changed reporting requirements in 1984, the average plant reported about 25 events per year. From 1981 to 1983 plants were reporting twice that number. In the short term, the barriers to learning from such frequent occurrences are great. However, in the long term, if the utility has the financial resources to support investigation and correction of the problem, the impact is likely to be positive.

Because the pressure to act is not as great as it is in the case of major violations, LERs rarely lead to plant shut-downs and are not likely to have a negative effect on efficiency. There is likely to be a lag between the recognition of a problem and its correction. In the short run, problem recognition will show up as poor performance. Only in the long run will the gains be consolidated in the form of better performance. LERs occurring in earlier time periods therefore are more likely to be positively associated with safety and efficiency. LERs occurring in recent time periods are likely to be negatively correlated with both indicators. Thus, the relationship between LERs and performance will manifest itself in fits and starts with declines occurring before the advances.

Learning, then, requires both the development of cognition and new patterns of behavior. It consists of both the insights and knowledge gained from experiencing problems and the modifications in structures, systems, and actions that are based on this knowledge. Recognizing a problem and developing conceptual schemes to interpret it needs to be followed by developing responses and actions that are based on the interpretation that has been made

(Fiol and Lyles, 1985). This distinction points to a paradox. The knowledge may be gained without an accompanying change in behavior. A reason could be lack of resources. Likewise, behavioral change could occur without cognitive development. Learning therefore requires both the ability to recognize problems and the resources and the capacity to make the requisite changes. Problem recognition is not enough. Without adequate resources the insights gained from knowledge cannot be translated into action.

Plants therefore need the resources to pay for safety improvements. Without adequate resources to invest in the personnel, training, and capital for continuous refinement and improvement, it is unlikely that managers can take the actions needed to improve performance. Two measures of resource availability were employed in this study: (i) profitability measured by return on assets indicates how much net income the utility has, controlling for size; and (ii) leverage as measured by the debt to equity ratio, which indicates the soundness of the utility's overall financial position and in particular its access to debt markets to fund capital investments. Profits and capital are needed to afford safety. The utility needs to earn sufficient profit or it has to go into debt in order to afford to make investments in safety and efficiency-enhancing capabilities. For organizational reflection, experience, and problem solving to take place and for new competencies and skills to be introduced into the organization, slack resources are essential (Miles, 1982).

Although simple learning can come from repetition, complex learning requires investment in a series of successively improving capital goods which create a different production environment (Arrow, 1963). New knowledge enters via the improved capital goods, the increased and therefore more expensive labor skills, the better materials, and the greater engineering and managerial expertise, which also cost money. Managers can influence and control this process by investing in actions that capture the advantages from these sources of progress. With regard to improvements in safety, Reason (1988) also emphasizes the importance of resources. He makes the distinction between active and latent failures. Active failures

> make their effects felt immediately. They are usually associated with the activities of the frontline operators...Latent failures, on the other hand, are those whose adverse consequences may lie dormant within the system for a long time, only becoming evident when they combine with other factors to breach the system's deficiencies.

Reason (1988) does case study analyses of TMI, Bhopal, Challenger, Chernobyl, and other major tragedies and shows that the pathway for propagating errors and violations always starts with the latent failures. The latent failures, he suggests, almost always originate

in resource scarcity - insufficient money, capital, personnel, and time to make needed safety improvements.

Resource problems clearly played a role in the Bhopal tragedy as they did in the TMI accident. Even though it was the third largest U.S. chemical producer, Union Carbide only ranked sixteenth in profitability. The Bhopal plant had lost money for three years in a row because of a downturn in the Indian economy and stiff competition from other pesticide producers marketing newly developed, less expensive products. With the fall in revenues, it became necessary to defer maintenance, lessen the rigor of training, and lay off workers. Similarly, the earnings of Metropolitan Edison, which owned and operated the TMI plant, had been disappointing in the mid to late 1970s due to a number of factors, including the fact that the utility had not been able to obtain adequate rate relief to cover increased fuel and operating costs. The company in 1974 had started an austerity program that included layoffs, early retirements, and reduced construction expenditures. Construction delays in building TMI and operating problems during the 1970s further added to Metropolitan Edison's financial woes.

The empirical evidence on the relationship between financial performance and safety is strong. Osborn and Jackson (1988) found a significant relationship when their independent variables were earnings and financial investment in nuclear power and their dependent variables were violations and plant reliability. Marcus (1988a) found significant correlations when his independent variables were profitability and long term debt and his dependent variables were LERs. The only study which does not show a positive relation between utility financial condition and some measure of safety is Hendrickson et. al. (1988). They find no connection between financial indicators at the time of application for permit to begin construction and the SALP ratings.

However, the relationship between financial capabilities and nuclear power safety, like the other relationships that have been discussed, is likely to be complex. The lag times may be long and the impacts indirect. Resources are both a cause and consequence of safety (see Marcus and Goodman, 1986 and McGuire, Sundgren, and Schneeweis, 1988). There is likely to be a feedback loop in which the availability of resources both affects and is affected by safety. While sufficient resources are needed to achieve an adequate level of safety, the availability of "excess" resources may be a sign that safety has been compromised. On the one hand, managers who are very strained for resources are unlikely to be able to operate their plants safely. A cause of tight financial conditions may be pressures from public utility commissions and consumers to lower rates. On the other hand, extreme profitability may be won at the expense of safety. Excessive attention to stockholders' return on investment may yield this result. Utilities constrained by very poor financial performance will not be able to

afford the investments in personnel and equipment that will assure an adequate degree of safety, while utilities which have achieved extremely strong financial performance may have done so by not taking necessary safety precautions.

4.3.3 Summary of the Hypotheses

In the broadest terms, the hypotheses suggest the following:

THE DEPENDENT VARIABLES

While safety and efficiency are different constraints, both affecting nuclear power plant performance, nuclear power plant performance is not a zero-sum game: safety does not have to be achieved at the expense of efficiency, nor does efficiency have to be achieved at the expense of safety.

THE INDEPENDENT VARIABLES

Five hypotheses concern relatively stable conditions (e.g. region, age, size) over which nuclear power managers have little control. Five suggest how nuclear power plant managers adjust their behavior in response to changing conditions (major violations, LERs, profit, and leverage). Relatively rare occurrences like the major violations capture their immediate attention. There is not enough time for them to adjust in a way that would enhance both safety and efficiency. The nuclear power plant managers, therefore, achieve a higher level of safety at the expense of efficiency. Unlike major violations, LERs occur less frequently. They also appear to be less severe, which affects how nuclear power plant managers respond to them. In the short run, the nuclear power managers do little to correct for the deficiencies indicated by the LERs. However, in the longer run, the managers adjust to the information in the LERs. In fact, the hypothesis is that the more LERs a plant has, the safer and more efficient it ultimately will be. Since the managers take time adjusting to the information in the LERs, they can use this information as a source for improving both safety and efficiency. To make productive use of this information, however, resources must be available. In the short run, these resources will not add to safety or efficiency. On the contrary, higher levels of profit may be a sign that improvements in safety and efficiency have been deferred. The effects of using profit and debt to pay for an increased level of safety and efficiency are likely to be felt only in the longer run.

4.3.4 Estimation

The hypotheses were tested using regression analysis. A set of equations were specified with each of the safety and efficiency indicators as dependent variables and the factors hypothesized to influence safety and efficiency as independent variables.

wo kinds of underlying characteristics were examined. To test for egional effects, dummy variables were entered for each region xcept Southwest. To test for reactor supplier effects, dummy ariables were entered for each supplier except General Electric. hus, the dummy variable parameters should be considered as ifferences from the Southwest performance and General Electric erformance.

he model hypothesizes that the influence of major violations, ER's, Debt/Equity, and ROA occurs over time: a number of past alues of these variables influence outcomes in the subsequent eriod. Substantively, this reflects the likelihood that it takes time to make changes in plants so current operations are likely to reflect responses to problems and finances several years previously.

The model would consequently look as follows:

Outcome = a_0 Plant Age
+ a_1 Major Violations(1985) + a_2 Major Violations(1984)
+ a_3 Major Violations(1983) + a_4 Major Violations(1982)
+ a_5 Major Violations(1981)
+ a_6 LER's(1985) + a_7 LER's(1984) + a_8 LER's(1983) + a_9 LER's(1982) + a_{10} LER's(1981)
+ a_{11} ROA(1985) + a_{12} ROA(1984) + a_{13} ROA(1983) + a_{14} ROA(1982) + a_{15} ROA(1981)
+ a_{16} Debt/Equity(1985) + a_{17} Debt/Equity(1984) + a_{18} Debt/Equity(1983) + a_{19} Debt/Equity(1982) + a_{20} Debt/Equity(1981)
+ a_{21} Northeast + a_{22} South + a_{23} Midwest + a_{24} West
+ a_{25} Babcock & Wilcox + a_{26} Combustion Engineering + a_{27} Westinghouse
+ a_{28} Number of Plants + a_{29} Plant Size + e

where the outcome is one of the efficiency or effectiveness variables.

The lagged variables in this model present two major estimation difficulties. First, the values in different years for some of these variables (e.g., Debt/Equity) are likely to be highly correlated. Second, with five years of lag values on each variable and from 48 to 67 usable observations (since only commercial plants could be used), the number of estimated parameters would be very high relative to the number of observations. These are standard problems whenever this kind of lag structure appears in a model.

One standard procedure to handle such problems is called "polynomial distributed lags." If one assumes that the parameters for a given variable (a's in the equation above, say for example a_1 to a_5 for major violations) follow some smooth function over time, they can be approximated by a Taylor expansion. The model can then be transformed using the Taylor expansion of the function

describing the parameters and the transformed model estimated. Estimates of the original a's can then be calculated from these estimates. Most standard econometric texts cover the technique, (see for example, Johnston, 1984). The procedure normally handles colinearity among the original variables and reduces the number of parameters to estimate.

We chose to use polynomial distributed lags to estimate the regressions. Consequently, it was assumed that the parameters on the lags would follow a continuous functional form approximated by a polynomial and so could be estimated using polynomial distributed lags. Higher order polynomials were tested and where higher orders were not statistically significant, lower order polynomials were used. The SAS polynomial distributed lag program was used for estimation.

As specified in the research contract, the data used was limited by what was readily available. The regressions, even with the polynomial distributed lags, estimate a large number of parameters with relatively little data. Consequently, the results of these regressions should be interpreted with caution. They represent tentative first efforts at complicated modeling of these processes rather than final results of extensive data analysis.

4.4 Results of the Empirical Analysis

The variables used to test the hypotheses are presented in Table 4.3. The means and standard deviations of these variables can be found in Table 4.4. The correlation matrix for all the variables in the analysis is in Appendix D. Table 4.5 shows the tests for the hypotheses about the dependent variables. Tables 4.6 and 4.7 show the tests for the hypotheses concerning the relationships between the independent and dependent variables. Table 4.6 gives the results when the independent variables are regressed against the safety indicators, Table 4.7 when the independent variables are regressed against the efficiency measures (critical hours and outage rates) and the SALP ratings. Tables 4.8 and 4.9 are summary tables which assess how well the hypotheses predicted the outcomes.

4.4.1 How Well the Hypotheses Predict the Outcomes: the Dependent Variables

As can be seen from Table 4.5, the evidence supports Hypothesis 4.1. The efficiency measures (critical hours and outage rate) are significantly correlated with each other ($p < .001$). The more critical hours recorded by the plant the lower the outage rate. Hypothesis 4.2 is also supported with the exception of safety system failures: seven of the ten possible correlations among the safety indicators are significant and positive ($p < .05$ or better). Scrams have positive and significant correlations with three of the

Table 4.3 Variable Definitions

Variable Label	Definition
SCRAMM	Average Scrams per quarter from second quarter 1985 to first quarter 1987
SSACTUAM	Average Safety System Actuations per quarter from second quarter 1985 to first quarter 1987
SIGEVENT	Average Number of Significant Events per quarter from second quarter 1985 to first quarter 1987
SSFAILM	Average Safety System Failures per quarter from second quarter 1985 to first quarter 1987
CRITHRM	Average Critical Hours per quarter from second quarter 1985 to first quarter 1987
OUTAGESM	Average Forced Outages per quarter from second quarter 1985 to first quarter 1987
OUTRATEM	Average Outage Rate per quarter from second quarter 1985 to first quarter 1987
SALPTOT5	Salp in 1985
PLANTSIZ	Plant Size in net MWe
BABWILSN	Designed by Babcock & Wilcox
COMBENG	Designed by Combustion Engineering
WESTINGH	Designed by Westinghouse
NORTHEAS	Northeast Region
SOUTH	South Region
MIDWEST	Midwest Region
WEST	Western Region
AGE	Age in years as of 1984
NOPLANTS	Number of plants owned by the utility
NOMAJV81 - 85	Number of major violations in a given year (1981 to 1985)
LER81 - 85	Number of licensee event reports in a given year (1981 to 1985)
DE81 - 85	Debt to equity ratio for a given year (1981-1985)
ROA81 - 85	Return on assets for a given year (1981-1985)

Table 4.4 Descriptive Statistics

VARIABLE	N	MEAN	STD DEV	MINIMUM	MAXIMUM
Scrams	51	0.944	0.6316	0.00000	3.286
Safety System Actuations	71	0.528	0.4847	0.00000	2.000
Significant Events	71	0.461	0.3718	0.00000	2.125
Safety System Failures	71	0.629	0.5102	0.00000	2.125
Critical Hours	71	1459.030	483.1092	0.00000	2042.725
Forced Outages	71	0.924	0.9683	0.00000	6.310
Outage Rate	71	15.873	20.5626	0.12500	87.500
SALP's 1985	53	8.226	2.0907	4.00000	12.000
Plant Size	74	818.176	261.5885	63.00000	1270.000
Babcock & Wilcox	74	0.081	0.2748	0.00000	1.000
Combustion Engineering	74	0.135	0.3442	0.00000	1.000
Westinghouse	74	0.432	0.4988	0.00000	1.000
Northeast	74	0.243	0.4320	0.00000	1.000
South	74	0.365	0.4847	0.00000	1.000
Midwest	74	0.270	0.4471	0.00000	1.000
West	74	0.081	0.2748	0.00000	1.000
Age	74	12.284	5.8766	2.00000	28.000
No. of Plants	74	4.041	2.6967	1.00000	10.000
No. of Major Violations 1981	74	1.338	2.3424	0.00000	10.000
No. of Major Violations 1982	74	0.730	1.3477	0.00000	8.000
No. of Major Violations 1983	72	1.472	1.8986	0.00000	8.000
No. of Major Violations 1984	73	1.068	1.5575	0.00000	8.000
No. of Major Violations 1985	72	1.097	2.0291	0.00000	10.000
LER's 1981	74	45.784	41.5363	0.00000	188.000
LER's 1982	74	50.662	42.3392	0.00000	172.000
LER's 1983	74	54.730	42.3370	0.00000	169.000
LER's 1984	74	25.297	19.2665	0.00000	94.000
LER's 1985	74	29.041	21.1948	0.00000	102.000
Debt/Equity '81	73	1.604	0.3120	1.02547	2.669
Debt/Equity '82	73	1.543	0.3635	0.93452	3.566
Debt/Equity '83	74	1.478	0.2971	0.68517	2.691
Debt/Equity '84	74	1.501	0.2845	0.72219	2.539
Debt/Equity '85	74	1.588	0.4187	0.91358	4.418
ROA 1981	73	0.036	0.0095	0.00406	0.061
ROA 1982	73	0.038	0.0112	0.00651	0.072
ROA 1983	74	0.044	0.0103	0.01254	0.079
ROA 1984	74	0.044	0.0108	0.01084	0.072
ROA 1985	74	0.041	0.0167	-0.04522	0.073

Table 4.5 Correlation of Safety Indicators, Efficiency Measures, and SALP Scores

	SAFETY INDICATORS					EFFICIENCY MEASURES		SALP
	1	2	3	4	5	6	7	8
1. SCRAMS	1.00	.68**	.32**	-.17	.55***	.26	-.18	-.17
2. Significant Events		1.00	.38**	.27**	.38***	-.07	.03	.34**
3. Forced Outages			1.00	.11	.26*	-.10	.14	-.00
4. Safety System Failures				1.00	.06	-.29**	.16	.37**
5. Safety System Actuations					1.00	-.13	.20	.12
6. Critical Hours						1.00	-.88**	.69***
7. Outage Rate							1.00	.55***

(Variables are averages per quarter, from second quarter 1985 to first quarter 1987)

*p < .05 ** p < .01 *** p < .001

Table 4.6 Safety Related Indicator Regression[1]

	Scrams[2]	Significant Events	Forced Outages	Safety System Actuation	Safety System Failures
Intercept	3.570 (0.974)	2.278*** (0.838)	4.211** (2.269)	0.378 (1.169)	0.148 (1.255)
Northeast	-0.013 (0.265)	-0.319 (0.259)	0.850 (0.722)	0.059 (0.372)	0.140 (0.392)
South	-0.745** (0.274)	-0.442* (0.258)	0.168 (0.720)	0.334 (0.371)	0.147 (0.390)
Midwest	-0.823*** (0.285)	-0.582** (0.265)	0.020 (0.740)	0.220 (0.381)	0.265 (0.400)
West	2.010*** (0.409)	-0.212 (0.290)	0.383 (0.808)	0.614 (0.416)	0.330 (0.438)
Babcock and Wilcox	0.080 (0.240)	0.227 (0.194)	2.136*** (0.529)	0.184 (0.273)	-0.489* (0.281)
Combustion Engineering	-0.158 (0.196)	0.073 (0.157)	0.337 (0.423)	0.140 (0.218)	-0.356 (0.228)
Westinghouse	-0.002 (0.188)	0.034 (0.110)	0.197 (0.303)	-0.087 (0.156)	-0.490** (0.163)
Age	-0.042* (0.023)	-0.009 (0.019)	-0.065 (0.051)	0.011 (0.026)	0.021 (0.027)
Plant Size	-0.0004 (0.0005)	-0.00003 (0.0004)	-0.001 (0.001)	0.001 (0.001)	0.0003 (0.001)
Number of Plants	0.061** (0.029)	0.001 (0.023)	0.098 (0.065)	-0.048 (0.033)	-0.020 (0.035)
Major Violations 1985	-0.167*** (0.031)	0.003 (0.020)	-0.097* (0.056)	0.009 (0.029)	0.039 (0.031)
Major Violations 1984	-0.060** (0.025)	0.005 (0.014)	-0.061 (0.038)	-0.004 (0.019)	0.024 (0.020)
Major Violations 1983	0.004 (0.028)	0.007 (0.010)	-0.025 (0.028)	-0.017 (0.015)	0.008 (0.015)
Major Violations 1982	0.023 (0.022)	0.009 (0.013)	0.012 (0.036)	-0.030 (0.019)	-0.007 (0.019)
Major Violations 1981	-0.001 (0.030)	0.010 (0.019)	0.048 (0.054)	-0.043 (0.028)	-0.022 (0.029)

Table 4.6 (continued)

	Scrams[2]	Significant Events	Forced Outages	Safety System Actuation	Safety System Failures
LER's 1985	0.002 (0.003)	0.003 (0.002)	0.012* (0.006)	0.005 (0.003)	-0.001 (0.002)
LER's 1984	0.016*** (0.005)	-0.0002 (0.001)	0.001 (0.003)	-0.0003 (0.001)	-0.001 (0.002)
LER's 1983	0.006*** (0.002)	-0.002** (0.001)	-0.003 (0.002)	-0.002* (0.001)	-0.0002 (0.001)
LER's 1982	-0.006** (0.002)	-0.002*** (0.001)	-0.001 (0.002)	-0.001 (0.001)	0.0002 (0.001)
LER's 1981	-0.0004 (0.002)	0.0003 (0.001)	0.007* (0.003)	0.005*** (0.002)	0.001 (0.001)
Debt/Equity 1985	0.094 (0.122)	-0.140 (0.127)	-0.057 (0.260)	-0.091 (0.134)	-0.294 (0.190)
Debt/Equity 1984	-0.254* (0.143)	0.443 (0.319)	-0.114 (0.151)	-0.055 (0.078)	1.369*** (0.480)
Debt/Equity 1983	-0.382** (0.174)	-0.233* (0.134)	-0.172 (0.118)	-0.018 (0.061)	0.125 (0.190)
Debt/Equity 1982	-0.291*** (0.101)	-0.728** (0.284)	-0.230 (0.202)	0.018 (0.104)	-1.179*** (0.418)
Debt/Equity 1981	0.018 (0.282)	0.401 (0.244)	-0.287 (0.321)	0.054 (0.165)	0.306 (0.361)
Return on Assets 1985	2.346*** (6.783)	5.832 (4.371)	-2.736 (10.017)	-2.824 (5.161)	-4.874 (5.574)
Return on Assets 1984	-9.042* (5.221)	-7.311** (3.547)	-5.482 (5.334)	-2.420 (2.748)	-3.025 (2.988)
Return on Assets 1983	-21.670*** (6.316)	-12.259*** (4.269)	-8.227** (3.287)	-2.015 (1.694)	-1.176 (1.859)
Return on Assets 1982	-15.358*** (3.939)	-9.013*** (2.794)	-10.973 (6.885)	-1.610 (3.547)	0.673 (3.828)
Return on Assets 1981	9.713 (11.764)	2.427 (7.344)	-13.719 (11.758)	-1.205 (6.058)	2.521 (6.521)
Adj R^2	.79	.29	.21	.12	.13
F	8.89***	2.25**	1.93**	1.48	1.52
N	48	67	67	67	67

[1] * $p < .1$, ** $p < .05$, *** $p < .01$. Standard errors in parentheses under parameter estimates.
[2] Dependent variables are averages from quarter 2, 1985 to quarter 1, 1987.

Table 4.7 Regressions on Efficiency Indicators and SALP's[1]

	Critical Hours[2]	Outage Rate	SALP 1985[3]
Intercept	2888.112*** (723.193)	-60.070 (37.390)	6.524* (3.349)
Northeast	-71.132 (230.218)	-2.868 (12.075)	-3.908*** (1.173)
South	-263.215 (229.538)	11.856 (12.014)	-1.127 (0.979)
Midwest	-360.473 (235.758)	15.138 (12.350)	-0.616 (1.017)
West	-230.774 (257.549)	4.842 (13.473)	-1.272 (1.218)
Babcock and Wilson	-457.929*** (168.656)	20.384** (8.529)	0.120 (0.832)
Combustion Engineering	-246.935* (134.827)	12.222* (6.926)	-0.190 (0.685)
Westinghouse	128.207 (96.707)	-1.850 (4.940)	0.212 (0.506)
Age	-29.863* (16.269)	1.429* (0.840)	0.095 (0.087)
Plant Size	-1.020*** (0.365)	0.060*** (0.019)	0.002 (0.002)
Number of Plants	52.246** (20.659)	-3.932*** (1.079)	-0.162 (0.100)
Major Violations 1985	-137.510*** (17.902)	5.740*** (0.939)	0.470*** (0.079)
Major Violations 1984	-100.174*** (11.998)	3.907*** (0.629)	0.352*** (0.056)
Major Violations 1983	-62.837*** (9.021)	2.074*** (0.470)	0.233*** (0.048)
Major Violations 1982	-25.501** (11.523)	0.241 (0.600)	0.114* (0.061)
Major Violations 1981	11.836 (17.267)	-1.592* (0.901)	-0.005 (0.086)

Table 4.7 (continued)

	Critical Hours[2]	Outage Rate	SALP 1985[3]
LER's 1985	-0.363 (2.027)	-0.146** (0.071)	0.005 (0.007)
LER's 1984	1.091 (0.890)	-0.096** (0.046)	0.003 (0.004)
LER's 1983	1.329* (0.689)	-0.045* (0.025)	0.002 (0.002)
LER's 1982	0.351 (0.484)	0.006 (0.020)	0.001 (0.002)
LER's 1981	-1.842* (1.006)	0.057 (0.038)	-0.001 (0.004)
Debt/Equity 1985	-1.287 (82.734)	0.739 (4.340)	-0.248 (0.362)
Debt/Equity 1984	-16.538 (48.213)	1.669 (2.522)	-0.076 (0.209)
Debt/Equity 1983	-31.789 (37.670)	2.599 (1.943)	0.097 (0.201)
Debt/Equity 1982	-47.039 (64.254)	3.529 (3.330)	0.269 (0.348)
Debt/Equity 1981	-62.290 (102.241)	4.450 (5.319)	0.441 (0.535)
Return on Assets 1985	6682.694* (3193.126)	-170.034 (167.361)	-13.380 (15.286)
Return on Assets 1984	4186.023* (1700.313)	-110.710 (89.120)	-11.994 (8.289)
Return on Assets 1983	1689.352 (1047.893)	-51.387 (54.712)	-10.597** (5.153)
Return on Assets 1982	-807.319 (2194.791)	7.936 (114.545)	-9.201 (10.353)
Return on Assets 1981	-3303.990 (3748.085)	67.259 (195.800)	-7.805 (17.625)

Table 4.7 (continued)

	Critical Hours[2]	Outage Rate	SALP 1985[3]
Adj R^2	.68	.51	.72
F	8.46***	4.86***	7.95***
N	67	67	49

1 * p < .1, ** p < .05, *** p < .01

2 Quarterly averages from quarter 2, 1985 to quarter 1, 1987.
Standard errors in parentheses under parameter estimates.

3 Dependent variable is plant's SALP rating in 1985.

indicators. Significant events are significantly and positively correlated with all the indicators. Safety system failures, however, are not significantly and positively correlated with scrams, forced outages, or safety system actuations. Thus, they appear to be a different dimension of safety. None of the safety indicators is significantly and positively related to the efficiency measures, critical hours or outage rate: the evidence, therefore, conforms to Hypothesis 4.3. Safety system failures is significantly and negatively correlated with critical hours. Hypothesis 4.4, therefore, is supported with the exception of safety system failures. Again, safety system failures appears to be different than the other indicators.

Two of the safety indicators, significant events and safety system failures, and both of the efficiency measures are significantly and positively correlated with the SALP ratings. This finding is in conformity with what Hypothesis #4.5 predicts. The SALP ratings point to the contradiction between efficiency and safety. Plants with good SALP ratings (low SALP scores) should be safer and more efficient, but what is found is that while plants with the good SALP ratings are safer they are not more efficient. Since the SALP ratings are from 1985 before the 1985-87 safety and efficiency results have been established they may be influencing these results. The SALP scores may be a signal to management that something is wrong and that the plant cannot run at full capacity until the safety problems are corrected. Thus, the SALPs may be an influence on learning. The predicted and actual relationships between efficiency and safety are summarized in Table 4.8.

4.4.2 How Well the Hypotheses Predict the Outcomes: the Independent Variables

Tables 4.6 and 4.7 show that the independent variables are better at explaining critical hours and outage rate than they are at explaining the safety outcomes. The adjusted R squared for the efficiency measures is higher; for critical hours it is .68 and for the outage rate it is .51. The exception is scrams. Here is a safety indicator where the adjusted R squared is .79. In these three cases, critical hours, the outage rate, and scrams, the amount of variance explained is large: the regressions are significant at the $p < .01$ level. Two of the other safety indicators, significant events and forced outages, also are significantly explained by the regressions. For significant events, the adjusted R squared is .29 and for forced outages it is .21. These results are significant at $p < .05$ level. The regression results, however, do not significantly explain the remaining safety indicators, safety system actuations and safety system failures. With respect to the SALP scores, the adjusted R squared is .72 which is also significant at the $p < .01$ level.

Tables 4.6 and 4.7 show that Hypothesis 4.6.1.a is partially confirmed. Region has an effect on safety, but not on efficiency.

Table 4.8 Summary of Predicted and Actual Relationships Between Efficiency and Safety (Correlations and p-values are shown in Table 4.5)

	Efficiency Measures		Safety Indicators		SALP Ratings	
	Predicted	Actual	Predicted	Actual	Predicted	Actual
Efficiency Measures	+*	+*	0	0	+*	-*
Safety	0	0	+*	+*	+*	+*

0 = no relationship
+ = positive relationship
- = negative relationship
* = significant relationship

Plants in the South and Midwest have significantly fewer scrams and significant events, while plants in the West have significantly more scrams. These regional differences with regard to safety are not easy to interpret. As discussed previously, it is not clear what they should be attributed to -- variations in NRC's enforcement philosophy, regional cultures, labor management practices, etc.? In light of the better safety record of the plants in the South and Midwest, it is surprising that the plants in the Northeast have significantly better SALP scores. One would think that the SALP scores would be better in regions where scrams and significant events were reduced. The simplest explanation is that the SALPs are a judgment measure and the regions calibrate it differently. Another explanation is that a relatively low SALP score influences subsequent performance. The scores given in the South and Midwest may provide a signal to managers that something has to be done to improve performance.

Hypothesis 4.6.b deals with reactor supplier. Tables 4.6 and 4.7 show that this variable has an effect on both the safety indicators and the efficiency measures of critical hours and outage rate. Babcock and Wilcox reactors have significantly more forced outages and General Electric reactors significantly more safety system failures. Critical hours and outage rates of the Babcock and Wilcox and Combustion Engineering reactors are significantly lower. Hypothesis 4.6.b therefore is confirmed.

Hypothesis 4.7.a concerns the number of plants per utility. Tables 4.6 and 4.7 show that controlling for the other variables the more plants per utility, the more efficient these plants are likely to be (as measured by critical hours and outage rates) and the more scrams they are likely to have. The number of plants per utility, as expected, is negatively related to safety and positively related to efficiency. Hypothesis 4.7.a therefore is confirmed. The meaning of these results, however, remains in doubt. Do the leaders of utilities that have made a greater commitment to nuclear power operate with more boldness, thus challenging safety limits to increase efficiency? Are they "riverboat gamblers" as Osborn and Jackson (1988) maintain, or is a bureaucratic imperative at work with more plants per utility signifying a fixation with a single goal, efficiency, and a rigidity that prevents creative problem solving and proactive attention to safety?

Hypothesis 4.8.a deals with age, the first component of the concept we have called technological sophistication. The second component is size. Size and age (see the correlation matrix in Appendix D) are highly negatively correlated (-.82). Newer plants tend to be larger, older plants smaller. Tables 4.6 and 4.7 show that the older plants have significantly fewer scrams; in this way they are significantly safer. In addition, although not statistically significant, all other coefficients of age and size with scrams, significant events and forced outages equations are negative as hypothesized. However, new plants are also more efficient. Thus,

Hypothesis 4.8.a is only partially confirmed. Part of it is actually contradicted. Except insofar as equipment obsolescence and maintenance problems may plague the old plants and affect their efficiency records, older plants were not expected to have lower efficiency ratings. If, as plants get older, they are off-line more, this may contribute to their having fewer scrams. Thus, a better safety record may be a function of less use rather than increased experience. Thus, the results do not allow one to say that over time, as plants mature, there is a learning effect with regard to safety, that plants become more safe as they age because of greater experience.

Hypothesis 4.8.b deals with size, the second component of technological sophistication. Tables 4.6 and 4.7 show that size is significantly related to the efficiency measures of critical hours and outage rate, but not to safety. Controlling for the other variables, larger plants are significantly less efficient than smaller plants, but they are not significantly less safe. The fact that they are significantly less efficient may be why they are not less safe. Since they are shut-down a greater proportion of the time, they have fewer opportunities for having safety problems. Thus, the results confirm a part, but not all, of Hypothesis 4.8.b. When taken together, the results about size and age are somewhat surprising since size and age are so highly negatively correlated, and yet it is the old and the large plants that are less efficient.

Hypothesis 4.9.a concerns major violations. The following summarizes 'the evidence with regard to the impact of major violations on the safety and the efficiency indicators, controlling for the other variables:

*The more major violations a plant has in 1985 and 1984, the fewer scrams it has in 1985-1987.

*The more major violations a plant has in 1985, the fewer the forced outages it has in 1985-1987.

*The more major violations a plant has in 1985, 1984, 1983, and 1982, the fewer critical hours it has in 1985-1987.

*The more major violations a plant has in 1985, 1984, and 1983, the higher the outage rate it has in 1985-1987.

These relationships appear to bear out the predicted effects of major violations. Hypothesis 4.9.a., therefore, is supported. Major violations have a positive effect on safety and a negative effect on efficiency. Their impact on safety is immediate, but what may be causing this impact is that plant use has been curtailed while management is trying to figure out what has gone wrong and trying to correct the deficiency. An interesting anomaly which is consistent with our theory shows that the more major violations a

plant has in 1981 the lower its outage rate in 1985-87. This finding suggests that in the long run positive learning about efficiency can occur from the major violations.

The more major violations that a plant has in 1985, 1984, 1983, and 1982, the worse its 1985 SALP ratings. These findings suggest that the SALP ratings are heavily influenced by the major violations, which is not surprising given the fact that it is the same inspection and enforcement officials who give the major violations and assign the SALP ratings.

For Hypotheses 4.10.a-4.10.d, time plays an important role in the predictions. The effects of LERs, profit, and debt/equity ratio are expected to vary depending on when they occur. More recent LERs, profit, and debt should have a different effect than earlier LERs, profit, and debt. To be consistent in the definitions of more "recent" and "earlier" the following conventions have been adopted: "recent" LERs, profit, and debt refers to the figures for the years 1985 and 1984, while "earlier" LERs, profit, and debt refers to the figures for the years 1983 and 1982. The year 1981 will be treated as a base year, and any systematic relationships affecting the independent and dependent variables in this year will be noted.

Hypothesis 4.10.a concerns the recent LERs. The following summarizes the evidence with regard to the impact of the recent LERs on the safety and efficiency indicators, controlling for the other variables:

*The more LERs a plant has in 1985, the more forced outages it has in 1985-1987.

*The more LERs a plant has in 1984, the more scrams it has in 1985-1987.

*The more LERs a plant has in 1985 and 1984, the lower the outage rate it has in 1985-1987.

The pattern here seems to be one in which plant managers do not learn safety lessons from recent LERs, but they do learn efficiency lessons. Safety continues to deteriorate at the same time that efficiency is rising. An interpretation of this finding would be that safety has been compromised for the sake of efficiency. Hypothesis 4.10.a, therefore, is only partially supported. Recent LERs have a negative effect on safety, as predicted, but they also have a positive effect on efficiency, which was not expected.

Hypothesis 4.10.b concerns the earlier LERs. The following summarizes the evidence with regard to the impact of earlier LERS on the safety indicators controlling for the other variables:

*The more LERs a plant has in 1983 and 1982, the fewer significant events it has in 1985-1987.

*The more LERs a plant has in 1982, the fewer scrams it has in 1985-87.

*The more LERs a plant has in 1983, the fewer safety system actuations.

The one exception is that the more LERs a plant has in 1983, the more scrams it has in 1985-1987.

The following summarizes the evidence with regard to the impact of earlier LERs on the efficiency measures controlling for the other variables:

*The more LERs a plant has in 1983, the more critical hours the plant has in 1985-87.

*The more LERs a plant has in 1983, the lower the outage rate it has in 1985-1987.

On the whole, Hypothesis 4.10.b is supported. As predicted, earlier LERs have a positive effect on safety (there is the one exception that was noted) and a positive effect on efficiency as measured by critical hours and outage rate.

Hypothesis 4.10.c concerns the impact of recent profit and debt. The evidence with regard to the impact of these variables on the safety indicators is interesting. In conformance with the hypothesis, the regressions show that the resources which are immediately available are negatively related to safety:

*The more profitable a utility is in 1985, the more scrams its plants have in 1985-1987.

Here one interpretation is that safety has been compromised for the sake of profitability. It is also the case that, controlling for the other variables:

*The more profitable a utility is in 1984, the fewer scrams and significant events its plants have in 1985-1987.

*The higher a utility's debt to equity ratio in 1984, the fewer scrams its plants have in 1985-1987.

Here it appears that the availability of resources in the form of profit and debt contribute to a better safety record.

The impact of recent resources on efficiency measures does not support the original hypothesis. Recent resources are associated

with a higher level of efficiency, controlling for the other variables:

*The more profits a utility has in 1985 and 1984, the more critical hours its plants have in 1985-1987.

It appears as if managers use recent resources to achieve a higher level of efficiency. One interpretation is that efficiency is their first priority. Hypothesis 4.10.d is about the effects of earlier resource availability on nuclear power plant performance. The following summarizes the evidence:

*The more profit a utility has in 1983 and 1982, the fewer the number of scrams and significant events its plants have in 1985-1987.

*The higher the debt/equity ratio a utility has in 1983 and 1982, the fewer the number of scrams and significant events its plants have in 1985-1987.

*The more profit a utility has in 1983, the lower is its forced outage rate in 1985-1987.

*The higher the debt/equity ratio a utility has in 1982, the fewer safety systems failures its plants have in 1985-1987.

As predicted, earlier resources have a positive effect on safety; but there is no effect on the efficiency measures. Thus, Hypothesis 4.10.d is only partially supported. Recent resources have a beneficial effect on efficiency measures, while earlier resources have the more beneficial effect on safety. Table 4.9 summarizes the predicted and actual relationship between the independent and dependent variables.

4.4.3 Summing Up

Overall, nineteen out of twenty-six hypotheses are supported. (See Tables 4.8 and 4.9) Results not predicted were:

*Plant age has a negative effect on the efficiency measures, but a positive impact on the safety indicators.

*Recent LERs are positively related to the efficiency measures, but negatively associated with the safety indicators.

* SALP scores were significantly and positively related to the safety indicators, however, they also were significantly and negatively related to the efficiency measures.

Table 4.9 Summary of Predicted and Actual Relationships Between Environmental, Contextual, and Process Variables, and the Safety and Efficiency Measures (Betas and p-values are shown in Table 4.7)

	Efficiency		Safety	
	Predicted Relationship	Actual Relationship	Predicted Relationship	Actual Relationship
Region	*	0	*	*
Reactor Supplier	*	*	*	*
Plant Age	* +	* −	* +	* +
Plant Size	* −	* −	* −	0
# of Plants Per Utility	* +	* +	* −	* −
Major Violations	* −	* −	* +	* +
Recent (1984-85) LERs	* −	* +	* −	* −
Earlier (1982-83) LERs	* +	* +	* +	* +
Recent (1984-85) Resources	* −	* +	* −	*
Earlier (1982-83) Resources	* +	0	* +	* +

0 = no relationship + = positive relationship − = negative relationship * = significant relationship

*Region did not have a significant effect on the efficiency measures.

*It was predicted that plant size would have a significant negative effect on the safety indicators, but it did not.

*Recent resources have a significant, positive effect on the efficiency measures.

*It was predicted that resources recently available would have a significant, negative association with the safety indicators. The evidence, however, was conflicting.

*It was predicted that resources available earlier would have a significant, positive relation with the efficiency measures, however, there was no actual relationship.

4.5 Conclusions

What has been learned about nuclear power plant safety? First, the safety indicators are not the same as efficiency measures. The difference between these performance criteria do not lead them to be significantly negatively correlated, at least when efficiency is measured by critical hours and outage rate. Nuclear power plant management, therefore, is not a "zero-sum" game. However, what influences these efficiency measures to move in one direction may be precisely the same factors that influence the safety indicators to move in the opposite direction. Factors that had opposing impacts on the efficiency measures and safety indicators included plant age, number of plants per utility, major violations, recent LERs and to some extent recent resources.

With regard to the safety indicators, the findings were that:

1) Older plants tended to have significantly better records.

2) Fewer plants per utility tended to be associated with a significantly better safety record.

3) Major violations appeared to have the effect of significantly improving plant performance with respect to the safety indicators.

4) Recent LERs were significantly negatively related with the safety indicators, but earlier LERs had a significant positive relation.

5) Profitability, in particular earlier profitability, tended to be significantly positively related to the safety indicators.

The pattern of these findings are consistent with a view tha organizational learning does occur at nuclear power plants. In th short term, it appears to occur at the expense of efficiency Nuclear power plant usage is reduced as managers deal with th implications of major violations. In the longer term, efficienc and safety are not at odds. Learning requires problem recognitio (the LER data) and adequate resources (profit and/or debt) to deal with problems and correct deficiencies.

These findings only hold if a number of qualifications are mentioned. First, the model tested in this study explains the efficiency outcomes of critical hours and outage rates better than the safety outcomes. Among the safety measures, those that were better explained were scrams, significant events, and forced outages. The model was very limited in its ability to explain safety system actuations and safety system failures. Second, additional work is needed, especially in the area of emergent processes, because the ability to explain the safety indicators with the available concepts and data was not wholly satisfactory. This is discussed more fully in Chapter 6 where the policy implications of this study are developed.

5.0 PERFORMANCE INDICATORS USED BY INDUSTRY AND THEIR RELATIONSHIP TO MANAGEMENT AND ORGANIZATION

This chapter reviews performance indicators used by the nuclear industry which may directly or indirectly address management and organization issues and their impact on safety. It first reviews overall plant performance indicators developed by the Institute of Nuclear Power Plant Operations (INPO) and then reviews the specific indicators used by individual utilities. None of the INPO overall performance indicators directly address management and organization but they may be indirectly related to management performance. Some of the specific indicators used by utilities directly address administrative issues and may be directly related to management performance. Section 5.1 discusses the general findings from the review of INPO performance indicators. The results of the review of specific indicators used by individual utilities are presented in Section 5.2. Section 5.3 presents the conclusions and recommendations.

5.1 Inpo Overall Performance Indicators

Prior to actions of the Institute of Nuclear Power Operations (INPO), the systematic development of performance indicators by the nuclear industry was only loosely established. Most indicator programs were initiated as a result of the data reporting requirements to the North American Electrical Reliability Council in such areas as capacity factor, availability factor, heat rate and forced outages. Utilities typically built their indicator programs around specific information needs as they arose. If management was concerned about a problem, such as personnel errors, and suspected that the amount of overtime was a contributory cause, it would then ask for periodic reports on overtime worked and an indicator would be developed and used.

Starting in the early 1980's, INPO has undertaken an extensive effort to develop overall plant performance indicators. These indicators are aimed at plant system and equipment performance as it impacts economic and safety performance. Management and organization indicators generally must be inferred or derived from plant equipment and system performance. INPO is aware that its indicators are partially contradictory. In a letter from Dr. Zack T. Pate, President of INPO, to William J. Dircks, Executive Director for Operations at NRC, dated September 16, 1985, Pate spells out some of these contradictions, particularly that between efficiency, which is primarily an economic indicator, and safety, which may not be consistent with this economic indicator:

> Focusing on a narrow set or one indicator can be counterproductive to safety. For example, overstressing the achievement of a high capacity factor for the short term, or seeking

to set records for continuous service, could cause plant management and operational personnel to make non-conservative decisions with respect to safety. The same applies to reactor scrams and to some of the other indicators if considered in isolation. As a second example, while we believe that striving to reduce the number of scrams is a worthwhile goal, we do not believe that trying to drive this indicator to zero--or even that trying to match the Japanese record of less that 0.5 a year--is necessarily a good thing.

INPO recommends the establishment of long-term goals for a carefully selected set of overall indicators evaluated as a set of indicators without focusing excessive attention on isolated short-term performance with regard to any particular indicator. The advantage of this approach, Dr. Pate points out, is "plants that achieve a long-term record of good performance, as measured by a range of sound indicators, must be well-managed overall, and can be expected to have a higher margin of safety."

Ten overall performance indicators were proposed by INPO in 1985:

Equivalent Availability Factor
Safety System Unavailability
Unplanned Automatic Scrams While Critical
Unplanned Safety System Actuations
Forced (or Unplanned) Outage Rate
Thermal Performance (Heat Rate)
Fuel Reliability
Collective Radiation Exposure
Volume of Low-level Solid Radioactive Waste
Industrial Safety (Lost-time Accident Rate)

Of these ten, four clearly are efficiency, rather than safety measures. Five were selected as most suitable for use in initial efforts for setting long term goals and data collection. These include:

Equivalent Availability Factor
Unplanned Automatic Scrams While Critical
Collective Radiation Exposure
Volume of Low-level Solid Radioactive Waste
Industrial Safety (Lost-time Accident Rate)

Two of these (numbers 1 and 4) are efficiency measures. INPO has continued to refine their overall performance indicators since 1985. Slight modifications in name and/or definition have been made with Safety System Unavailability, Thermal Performance, and Fuel Reliability and data tracking efforts for these indicators are just getting underway.

The NRC also has established a performance indicator program for operating nuclear power plants and it is useful to compare NRC performance indicators with those of INPO. The seven current NRC performance indicators are listed below:

Automatic Scrams While Critical (Scrams)
Safety System Actuations (SSA)
Significant Events (SE)
Safety System Failures (SSF)
Forced Outage Rate (FOR)
Equipment Forced Outages Per 1000 Critical Hours (EFO)
Collective Radiation Exposure

Four of these are identical to the performance indicators used by INPO:

Automatic Scrams While Critical (same as Unplanned Automatic Scrams)

Safety System Actuations (same as Unplanned Safety System Actuations)

Forced Outage Rate

Collective Radiation Exposure

Of the remaining three, Safety Systems Failures is somewhat similar to INPO's Safety System Unavailability. Significant Events and Equipment Forced Outages per 1000 Critical Hours have no INPO counterparts.

The remainder of this section summarizes the INPO overall performance indicators and briefly discusses their potential relevance to management and organization issues and their impact on safety.

5.1.1 Equivalent Availability Factor

INPO adopted the definition used by the North American Electric Reliability Council (NERC) for calculating the equivalent availability factor. Simply stated this indicator is a ratio of available generation to maximum generation, expressed as a percentage. The quantity used for available generation considers the hours of full capacity availability, the hours of unit derated capacity and the hours of seasonal derated capacity.

In the years from 1980 to 1985, INPO reports the industry-wide average for this parameter remained nearly constant in the range of 58 percent to 61 percent. The historical data indicates significant margin for improvement. INPO observes that if the plants performing in the lower quartile of equivalent availability

factor had an average factor equivalent to the average of the upper three quartiles, the industry average would have been nearly 70 percent.

High equivalent availability factors are generally regarded to represent plants that are managed better and have a higher level of safety. High equivalent availability factors can, however, mask dormant or latent problems in safety systems that are in standby service during normal operation and are only tested during technical specification surveillance tests. If the plant operating philosophy preferentially gives priority, resources and importance to the production of power, the equivalent availability factor only measures the performance of the power conversion system and not the safety systems. It is this weakness that led to the development of safety system unavailability (Section 5.1.2) as an indicator. High performance in each of these indicators (i.e., high equivalent availability factor and low safety system unavailability) denotes a plant that places equal emphasis on power production and safety.

The validity of equivalent availability factor as a performance indicator of efficiency is fairly well accepted. With NERC specifying the calculation of the factor and its relative ease of measurement, equivalent availability factor is accepted as a valid indicator of effective plant management. As long as safety performance is not sacrificed to availability this indicator has significant value. However, as discussed previously, excessive attention to this indicator alone tends to motivate plant management toward the power conversion system rather than an appropriate balance of power production capability and safety.

5.1.2 Safety System Unavailability

This INPO indicator is defined as the probability that the system is unable to perform its intended function during the time that the reactor is in an operating mode that would normally require the availability of the safety system. Unavailability is caused by component failure or removal of components from service for corrective or preventive maintenance when the safety system is required to be available. System unavailability is calculated from component unavailable hours, using a model of the selected system. Therefore, it reflects not only the time the complete system is actually unavailable, but also includes a contribution due to partial system unavailability (e.g., one train of a multi-train system unavailable) (Pate, 1985).

Safety system unavailability is tied directly to the safety of the plant by measuring the status of safety systems when they are required to be operable. INPO has suggested that emergency AC power, the high pressure safety injection system, and the auxiliary feedwater system in PWRs be monitored. In BWRs, INPO recommends monitoring the unavailability of emergency AC power, high pressure

coolant injection or high pressure core spray system, and the reactor core isolation cooling or isolation condenser system.

In order to use this indicator, each utility will have to develop a model of the systems to be monitored. The rigor and accuracy of the system model will directly affect the validity of safety system unavailability as an indicator of plant safety. Plants would need to carefully record component and equipment times out-of-service for use in calculating safety system unavailability.

As mentioned in Section 5.1.1, safety system unavailability and equivalent availability factor should be used together to indicate the relative importance placed on safety in relationship to power production and to indicate the overall performance of the plant.

5.1.3 Unplanned Automatic Scrams While Critical

INPO defines unplanned automatic scrams as an actuation of the reactor protection system that results in a scram signal at any time when the unit is critical. The scram signal may result from exceeding a setpoint or may be spurious. Scrams planned as a part of special evolutions or tests and manual scrams are not counted for this indicator. These types of scrams are not to be discouraged since they are either testing the scram capability of the reactor protection system or the operator is attempting to place the reactor in a condition of greater safety (i.e., shutdown).

The number of scrams while critical is closely related to unit safety. Since unplanned automatic scrams are initiated to prevent the reactor from exceeding the safety limits and system safety settings, scrams usually indicate that something is wrong that could place the plant in a less safe condition. In addition, due to the fact that every scram challenges the safety systems and accumulates transient age on plant equipment, the absence of scrams is an indicator of good performance. In addition, recent attention to the number of unplanned scrams serves to sharpen control room operators and ensure their conservative operation of the plant. As an example, most operators, when faced with an inevitable scram, will attempt to shutdown the reactor in a controlled fashion, rather than allowing a scram.

Data to measure this indicator are easily obtained. The information is reported to NRC in licensee event reports and is generally reported to the Nuclear Plant Reliability Data System.

5.1.4 Unplanned Safety System Actuations

NPO describes this indicator as a safety system actuation that occurs when a setpoint for the system is reached or when a spurious/inadvertent signal is generated and major equipment is

actuated. The equipment that is considered in the actuation is the emergency core cooling system and AC emergency power.

This indicator is directly related to safety. Any unplanned actuation of a safety system indicates a setpoint or limit established for safety has been reached. The systems were selected because their actuation is considered to be a direct indication of a significant off-normal plant condition.

Utilities typically report data on unplanned actuations of safety systems under the requirements of 10 CFR 50.72 and 10 CFR 50.73. Problems in measuring the indicator arise, however, due to the inconsistent level of information reported.

Accurate measurement of unplanned safety system actuations will motivate utilities to be more aggressive in operator observation of plant parameters that indicate the plant is proceeding toward off-normal conditions that may cause a safety system actuation. Operators will be able to take actions to return the plant to normal conditions or begin orderly shutdown procedures prior to safety system actuations. Of course, some situations will occur more quickly than operators can respond, however for those that occur more slowly, operator attention to plant parameters will improve the safety of plant operation.

This indicator in conjunction with unplanned automatic scrams will provide information on off-normal conditions occurring at plants and motivate plant management to be more diligent in observing minor plant trends prior to reactor protection system actions or safety system actuations.

5.1.5 Forced (or Unplanned) Outage Rate

This INPO indicator is defined as the percentage of the planned available time for power generation that a nuclear unit was not available for generation due to forced outages. These forced outages result from equipment failures or other conditions that require the unit to be removed from service immediately or before the end of the next weekend. This definition is consistent with information provided to NERC.

This indicator is directly related to safety. The forced outage rate indicates conditions that require correction prior to continued operation. A unit with a high forced outage rate is experiencing failures and conditions that are outside the safety limits of operation or prevent the operation of the power conversion system. INPO recognizes limitations in forced outage rate as an overall indicator because it reflects only one type of unplanned outage. Other types of unplanned outages that would not be reported as forced outage rate are outages that result from unsuccessful attempts to place a unit in service or outages that

can be deferred until after the end of the next weekend but still result in the removal of the unit prior to the next planned outage.

Data for this indicator are already reported to a variety of sources and are relatively unambiguous within the limitations described above. Measurement of this indicator may encourage plant management and operators to attempt to continue operations past the end of the next weekend to preclude increasing the forced outage rate. Any motivation to continue operation with the plant in a condition that will eventually require a unit outage to correct constitutes operation in a less safe condition.

5.1.6 Thermal Performance (Heat Rate)

Unit heat rate is the thermal energy (measured in Btus) required to produce one kilowatt-hour of electrical energy. The data needed to report thermal performance is the total thermal energy produced and the total gross electrical energy produced. INPO considers gross heat rate a better indicator than net heat rate because the net heat rate at reduced power increases artificially.

This indicator does not have strong ties to safety. In fact, focused attention on heat rate tends to motivate plants to continue operation when deration or shutdown may be advantageous from a safety perspective. The indicator does, however, encourage utilities to maintain high efficiencies in the power conversion system and will result in good management of this aspect of the plant. If the utility applies the same rigor to the safety systems as to the power conversion system in the achievement and maintenance of a high heat rate, then safety is enhanced, however it is not measured by this indicator. Measurement of the heat rate in conjunction with the indicators of unplanned safety system actuations and unplanned automatic scrams gives a broad picture of overall unit health in both safety and efficiency.

5.1.7 Fuel Reliability

Fuel reliability measures the ability of the fuel burned in the reactor to achieve its design burnup levels without fuel rod failure. Direct inspection of fuel rods upon removal from the reactor is not always practical for measuring fuel reliability. Indirect measurement of fuel failure is more practical and involves the measurement of iodine activity in the primary coolant during operation. Since a failed fuel rod will release iodine activity to the coolant, the magnitude of the steady-state iodine dose equivalent provides a relative measure of the number and size of fuel rod failures in the core. This is a relative measure because the power level, fuel rod defect type, and the extent of the failure can affect the release rate of iodine to the coolant.

This indicator is more a measure of fuel design and manufacturing than it is a measure of plant operations and management. Of

course, the utility must purchase highly reliable fuel and verify that the required quality is received, however, plant operation short of major transients resulting in fuel damage does not affect fuel reliability. The measure is related to personnel safety through the exposure that plant staff may receive during operation with fuel failures and the potential for minor releases in the event of primary system relief valve openings or steam generator leaks and secondary system relief. Generally, technical specifications require maintaining the reactor coolant system iodine activity sufficiently low. Because of its lack of direct impact on nuclear safety, INPO has removed fuel reliability from the list of overall plant indicators.

5.1.8 Collective Radiation Exposure

This is a measure of the average collective radiation exposure to utility employees, contractors and visitors by unit. This indicator is an indirect measure of plant safety since plants with low collective radiation exposure are generally regarded as being well-managed in the control of plant contamination and efficient in the administration of the ALARA (maintaining radiation exposures as low as reasonably achievable) program. Excessive attention on this indicator without understanding other important facts at a plant can result in misleading assumptions about safety of the plant. For example, a plant with normally low collective radiation exposure may implement a major design change to the plant for safety or efficiency improvement during an outage that will increase the éxposure for the reporting period. While the indicator shows a negative trend (increased exposure) the overall safety of the plant or its operating efficiency may be improved by the design change.

On the other hand, the trend of collective radiation exposure may provide impetus for the plant to defer needed or desireable work on the unit in order to maintain low collective exposures. It is important that this indicator be considered only as a part of the set of indicators, as cautioned by Dr. Pate of INPO.

5.1.9 Volume of Low-Level Solid Radioactive Waste

This INPO indicator is a measure of the average annual volume of low-level solid radwaste generated (i.e., shipped or ready for shipment in final form) per unit by reactor type. This indicator is not a direct indicator of plant safety; it is important, however, in the national nuclear considerations from the standpoint of minimizing the generation of radwaste for disposal in repositories. The indicator does have some relationship to the efficiency and competence of the plant to manage the generation of waste by using resources wisely in contaminated areas. There can be a motivation, however, to restrict material supplies for use in maintenance at the plant to minimize radwaste generation. If this results in increased exposures or contaminations from the use of

contaminated tools or equipment in the radiation controlled areas of the plant, the indicator has a negative effect on personnel safety.

5.1.10 Industrial Safety (Lost-Time Accident Rate)

This is an important indicator of personnel safety levels achieved at a site and is universally regarded as an acceptable measure of safe working conditions and an active employee safety awareness program. The indicator measures the number of accidents that result in any injury which involves days away from work (at least one full workday other than the day of the injury) and the corresponding man-hours associated with the accident.

The Occupational Safety and Health Administration (OSHA) requires all employers to maintain an OSHA form 200 which tabulates all recordable injuries, including lost-time accidents. Most personnel departments maintain records of man-hours worked, therefore, the data for the indicator are readily available. The Edison Electric Institute also collects lost time accident rates for operating plants.

This is an important indicator of personnel safety and motivates plant management to create and maintain a safe working environment. Plants with low lost-time accident rates are regarded as well-managed and safe since all staff are concerned with each other's safety on the job.

5.2 Specific Performance Indicators Used By Utilities

Utilities generally collect and report internally a variety of parameters for management use in daily plant operation. Usually these indicators are born out of a need to solve specific problems that have arisen in the past and have been maintained in the utility's list of indicators since. As an example, a senior manager may wish to understand why the overtime level is so great in maintenance. The manager may then ask that certain parameters on work order status be reported to him or her as well as the employee absenteeism rate and plant staffing trends, such as number of vacant positions and hires. The development of the indicator systems at many of the plants result therefore from information needs rather than from a systematic analysis of plant performance information needs that considers indicator accuracy, relationship to safety, resistance to tampering, and other measures of indicator validity.

Based upon a limited review of specific utilities, a set of specific performance indicators (other than the INPO indicators discussed in Section 5.1) that are being used in such areas as operations, maintenance, technical, health physics/chemistry, administration, training, quality assurance, support services and material management has been identified. These include:

1. Unit Capacity Factor
2. Control Room Instrument Operability
3. Maintenance Work Request Status
4. Preventive Maintenance Status
5. Equipment Out-of-Service
6. Plant Modifications
7. Plant Drawing Update and Update Backlog
8. Non-Conformance Reports
9. Licensee Event Reports
10. Plant Contaminated Areas
11. Personnel Contaminations
12. Chemistry Out-of Specification
13. Plant Administrative Parameters
14. Plant Personnel Performance
15. NRC Violations
16. Training Performance
17. Quality Assurance Program Performance
18. Plant Materials/Spare Parts

These indicators collectively may be viewed as nuclear power plant managers' attempts to identify and solve problems. Most of the individual utility indicators can be grouped into categories related to problem solving.

Problem Prevention

chemistry out of specification
equipment out of service
control room instrument operability
preventive maintenance status
material spare parts

Problem Awareness

procedure deviations
personnel errors
non-conformance reports
QA audits
operating experience review
operating events reports
LERs
NRC violations

Problem Resolution

training/exam performance
plant modifications
maintenance work requests status
plant drawing update

If these efforts to identify and solve problems are successful, organizational learning takes place at the plant and it is better able to cope with future contingencies that might arise. Thus, two aspects of these utility indicators are important. First, they are important to the extent that they represent organizational problem solving and learning. Second, it is important to understand the way individual utilities and plants select these indicators and how the outcome of this selection process may affect ultimate performance.

The remainder of this section summarizes these performance indicators and briefly discusses their potential relevance to management and organization issues and their impact on safety.

5.2.1 Unit Capacity Factor

This indicator is similar to the unit availability factor in its intent to measure the ability of the unit to produce power, however the capacity factor is based on the actual net electricity generated instead of the capability to generate electrical power. Capacity factor, therefore, potentially introduces demand factors into plant performance. This is not too significant since most nuclear units are base-loaded generating stations and not load-following.

Capacity factor has the same relationship to safety as the availability indicator.

5.2.2 Control Room Instrument Operability

This indicator has two standard components. The first measures the number of control room alarms and annunciators activated during plant power operation. The second measures the number of control room instruments that cannot perform their intended function, regardless of the reason.

The measurement of control room alarms and annunciators gives an indication of plant performance according to design. Obviously, the greater number of alarms and annunciators indicates plant equipment is not performing as intended and requires operator attention to diagnose and correct the problems being indicated. This indicator has a strong motivation to eliminate nuisance repetitive, problem alarms and annunciators that go into alarm and then return to operating ranges. These alarms fatigue and annoy the control room operators and have the potential for dulling their alertness.

While control instrumentation important to safety is governed by Technical Specification limiting conditions for operation, a measure of the instruments out-of-service focuses attention on the

degree to which the plant is operating with limited instrumentation.

In both of these components, for enhancement of safety, it is important to distinguish between safety instrumentation and power production instrumentation.

5.2.3 Maintenance Work Request Status

This indicator is a specific measure of the progress of maintenance work at the unit. Typically, plant management will look at the number of maintenance work requests issued, closed, and remaining open to keep track of the progress and responsiveness of maintenance to plant needs.

5.2.4 Preventive Maintenance Status

Similar to the maintenance work request status, this indicator measures the preventive maintenance tasks that have been scheduled, completed, deferred, waived, and remain open. Since well-conceived and proper preventive maintenance is important to prevent failure of plant equipment, many urge the reporting of preventive maintenance status to a level higher than plant management. This amounts to fairly detailed overview of specific functions at the plant and can be misinterpreted easily. Overall management indicators of maintenance performance are being sought in support of NRC's maintenance rule that would measure the overall health of the maintenance organization. Preventive maintenance status should then be used to diagnose problems within maintenance once the overall indicator suggests a problem.

5.2.5 Equipment Out-of-Service

Some utilities use equipment out-of-service to measure performance of equipment important to power production. While this is a good measure of management attention to the power conversion system, excessive attention to these items can have a negative impact on safety. In conjunction with indicators of safety system availability and challenges, this indicator can provide valuable information on plant management emphasis with respect to safety.

5.2.6 Plant Modifications

Modifications to plant systems, structures, components and computer systems/software that are initiated, completed, and remaining open are tracked by some utilities to indicate the backlog and responsiveness of engineering and modification crews to needed changes in the plant. This measure, if directed at safety-related modification work, would provide management with an indication of engineering support of plant needs after initial startup. As with all attempts to measure completed items versus backlog of open items, these measurements can be manipulated significantly by

creating new holding categories, replacing older packages with new ones, or writing several jobs into one work package.

5.2.7 Plant Drawing Update and Update Backlog

As modifications and changes are made to a plant, it is necessary to update all drawings to reflect the current system or component configuration, logic and connections. Delays in updating drawings may allow operators, maintenance personnel, or plant engineers to make decisions based on outdated information. Tracking and trending this information can provide management with a measure of the adequacy of resources dedicated to this function. This measure can be manipulated to give desired results, as discussed in Section 5.2.5.

5.2.8 Non-Conformance Reports

Utilities write non-conformance reports (NCRs) in response to the quality assurance requirements in 10 CFR 50, Appendix B. These reports can be used to identify hardware or nonhardware-related deficiencies. Since NCRs address quality-related deficiencies, more effective management of quality and safety can be accomplished by assuring that NCRs are promptly processed to satisfactory closure. The typical parameters trended and evaluated are the number of NCRs issued, closed and backlogged. These parameters are vulnerable to manipulation.

5.2.9 Licensee Event Reports

Utilities submit licensee event reports (LERs) for all unusual occurrences to the NRC as required by 10 CFR 50.73. These reports address a wide range of occurrences, including equipment failures, personnel errors and plant emergencies. Trending and evaluation of the total number of LERs and the number of LERs by failure category (e.g., personnel error; design, manufacturing, construction, and installation deficiencies; external events; defective procedures; management/quality assurance deficiencies; and other deficiencies) can provide management with a picture of the weaknesses of the plant. This information can focus management attention on the areas needing improvement. Since the LERs focus on quality and safety-related deficiencies, these trends indicate the safety performance of the plant and the ability of plant management to address these deficiencies. Because the reporting criteria are established as law by NRC, it is difficult to manipulate the data. Weaknesses can occur in the identified failure causes depending on the rigor applied by plant staff. This weakness does not usually last long because plant QA staff audit NCRs and NRC regional inspectors review corrective action effectiveness.

5.2.10 Plant Contaminated Areas

Some utilities measure the square footage of the surface area contaminated during the reporting period (typically one month). This indicates the ability of plant management to control the buildup of contaminated areas in the plant that potentially increases occupational exposure to plant staff. While this parameter is not directly related to nuclear plant safety, it is a measure of management commitment to maintain radiation exposures ALARA. This indicator does not, however, indicate management commitment to decontaminate plant areas.

5.2.11 Personnel Contaminations

This indicator usually indicates the number of skin contaminations occurring in the reporting period. This is related to personnel safety and protection and indicates management commitment to ALARA. Personnel contaminations are reported to the NRC.

5.2.12 Chemistry Out-of-Specification

Some utilities measure several parameters with respect to reactor coolant system chemistry conditions out-of-specification. Total hours during the reporting period that chemistry was out-of-specification due to conductivity, chlorides or pH may be recorded and trended individually and combined. These parameters indicate the exposure of the primary system to adverse chemical environments. These indicators are important for long-term control of system degradation and aging due to accelerated attack of system materials. Management's ability to control chemistry is important to assure the long-term integrity of the system.

5.2.13 Plant Administrative Parameters

Several indicators of plant administration with respect to personnel issues may be recorded. These include plant staffing levels, staff turnover rates, and staff overtime. These items are used in many industries to gauge the morale of employees and give an indirect indication of their potential performance. This relationship is based on the assumption that the satisfied employee will work harder to maintain high levels of performance and strive to achieve higher levels of quality and excellence in their work. These parameters are, however, subject to manipulation.

5.2.14 Plant Personnel Performance

Two measures are used by some utilities to measure the performance of plant staff. These include the number of plant procedure deviations (i.e., personnel failure to follow procedures) and the number of personnel errors (including commission and omission). Procedure deviations can be measured from LER data and failure reports to the Nuclear Plant Reliability Data System (NPRDS).

Personnel errors are much harder to determine accurately, even though they are nominally included in LERs and NPRDS reports due to the elusive nature of determining errors. These parameters are related to safety performance.

5.2.15 NRC Violations

The number of NRC violations issued against a plant is one indication of failure of administrative controls over plant processes and staff. The data cannot be manipulated. The most significant information to be gained from NRC violations, in addition to total numbers which represent general attention to safety, is the compilation of repeat violations and the compilation of violation causes. Repeat violations and repetitive causes indicate management's inability to identify and implement effective corrective actions.

5.2.16 Training Performance

Utilities generally collect and trend data to indicate the effectiveness of plant training programs. Student hours of training, instructor classroom hours of training, and NRC exam performance can be used to measure the amount of training being conducted and the effectiveness of licensed operator training programs. Quantity of training alone is not an adequate measure of training quality and effectiveness, however in combination with NRC violations, procedure deviations and personnel-caused NCRs, training effectiveness can be evaluated. The safety implications of training are direct in that well-trained staff are less likely to suffer from errors.

5.2.17 Quality Assurance Program Performance

Several indicators of QA performance are measured. These include deficiencies discovered in QA audits and surveillances, and the status of the operating experience review program, the significant event reports, and the significant operating event reports. QA audit and surveillances deficiencies indicate the effectiveness of QA and the problems in the implementation of the QA program. These quality items can be related to safety if the various categories of deficiencies are identified and individually evaluated. The status of the experience review programs indicates whether plant management is devoting resources to learning from operating experience at other plants and using that information to improve plant safety. Each of these indicators is susceptible to the manipulation of counting and reporting schemes. The burden of measurement in these areas may skew licensee attention to those items being tracked by management while other unreported items are neglected.

5.2.18 Plant Materials/Spare Parts

Management of the spare parts inventory and warehouse can be measured through several parameters associated with materials and spare parts. The normal consumption of plant spares provides management with an indication of material usage and allows management to determine whether consumption is excessive, indicating a problem. Also measured is the number of expedited material procurements. This is an indication of accurate estimates of spare parts minimum and maximum stocks. These are indications of management's ability to control the consumption of resources.

5.3 Conclusions and Recommendations From Industry Performance Indicator Review

Nuclear utility representatives generally have resisted NRC work in developing performance indicators for management and organization. The industry performance indicator efforts underway are aimed at plant system and equipment performance as it impacts economic and safety performance. Nuclear utility representatives argue that good performance using the INPO overall performance indicators and the utility specific performance indicators reflect a well-managed plant with a higher margin of safety.

As shown in Section 5.1, some indirect information of management performance can be potentially obtained from the INPO overall performance indicators. The INPO indicators can be divided into the following categories:

Efficiency Safety	Plant Safety	Worker
Equivalent Availability	Safety System Unavailability	Radiation Exposure
Thermal Performance	Unplanned Automatic Scrams	
Fuel Reliability	Unplanned Safety System Actuation	Idustrial Safety
Volume Radwaste	Forced Outage Rate	

The INPO indicators suggest that efficiency might be an important management indicator, but the relationship between this indicator and various safety indicators is likely to be complex and require empirical study.

As shown in Section 5.2, individual utilities are using some performance indicators that are directly relevant to management and organization. The individual utility indicators suggest two additional broad indicator categories that should be of interest to NRC. First, the indicators can be viewed as efforts by nuclear power management to gain information for problem identification, prevention and mitigation. Thus, they are indicators of problem solving used for the purpose of organizational learning. Second, the overall issue on how individual utilities select indicators and what they do with them is relevant to management and organization. This issue is worthy of additional study, because it is a key attribute of management.

6.0 POLICY IMPLICATIONS

In this chapter we will consider the policy implications that can be derived from our analyses. These policy implications are described below:

1. While considerable progress has occurred in the empirical analysis of organizational and management factors as they relate to nuclear power, there is still much to be done. Promising management indicators suggested by early research included: (1) Structural Features of the Plant (Olson et. al, 1984: NUREG-3737); (2) Generic Safety Issue Backlogs (Olson et. al. 1988: NUREG/CR-5241); and (3) LER Codes, particularly personnel and procedural errors (Olson et. al, 1988: NUREG/CR-5241). Early research also excluded what might have been considered a promising indicator, i.e., the operator exam scores and pass rates. The research done here suggests two additional candidate indicators that warrant further consideration:

> (1) utility resources [return on assets (ROA) and debt to equity ratio] assessed against a time frame which reveals their influence on public safety; and
>
> (2) the lagged recognition and correction of problems that accompanies the reporting of major violations and licensee event reports (LER).

These indicators will be discussed later in this conclusion under Item 7.

2. However promising the research in organization and management factors has been so far, NRC and private researchers need to move beyond simple categories and easily measurable variables toward an analysis of the complex, dynamic processes that take place at nuclear power plants. The amount of variance that can be explained with the existing categories and data is, in some instances, very great, while in other instances, the existing categories and data provide little understanding and explanation of nuclear power plant performance. With the available data and concepts, efficiency outcomes such as critical hours and outage rate generally are better explained than safety indicators. Among the safety indicators the present research is better able to explain scrams, significant events, and forced outages than safety system failures and safety system actuations.

3. A better explanation of nuclear power plant performance can be achieved by understanding emergent processes. While the theoretical developments in this area are extensive, concepts that relate these theories to nuclear power have not been adequately

defined and the variables have not been adequately measured. A particularly useful examination of an emergent process (which could be done as a follow-up to this work on organizational learning) would examine how individual utilities select performance indicators, what indicators they do select, and how this process and its outcome (the indicators that have been selected) influence safety.

4. To begin to develop a better data base on organization and management, certain basic information about nuclear power plant organization and management needs to be collected on a regular basis by the NRC and kept current. This information includes figures on staffing (e.g. how many people at the plant and headquarters, in what categories, with what qualifications), budgeting (how much money is being spent for what purposes and by whom), and organization charts. This basic information would be extremely useful in moving towards an analysis of emergent processes.

5. NRC should consider how it can productively store, catalogue, and use the intensive qualitative information that is being gathered about organization and management practices by AEOD and the SALP inspectors. This information has potential for being an invaluable source of information on organization and management practices if it is standardized in an appropriate fashion and accumulated.

6. It is not enough to say that additional work is needed on the causes of safety outcomes. Better definition and conceptual rigor is required with respect to the safety outcomes themselves. Further validation of management indicators requires that appropriate dependent variables and measures of safety which have been justified and obtained broad acceptance be available.

7. Even with these reservations mentioned about the limitations of what can be done given the available concepts and data, research into the organization and management factors that influence safety outcomes has been promising and justifies the additional expense of continued involvement in this area. Key conclusions that NRC inspectors and investigators should keep in mind are:

a. Safety and efficiency (measured by critical hours and outage rates) are different performance categories. While they are not negatively correlated, an efficient plant is not necessarily a safe plant, nor is a safe plant necessarily an efficient plant. The work reported here shows that safety and efficiency are different attributes of nuclear power plant performance with different causes and consequences. Learning how to balance these different attributes is one of the key challenges of nuclear power plant management.

b. Nuclear power plants have different tendencies towards safe and efficient operations based on certain state conditions, i.e., environmental and contextual factors over which, after initial pre-production decisions are made, they have little control. Like other studies the present analysis shows that such factors as region, reactor supplier, age, size, and number of plants per utility all have a significant influence on performance.

c. An organizational characteristic of great promise is number of plants per utility. It has received support in a number of studies including this one. Fewer plants per utility is positively related to safety, while more plants is positively related to efficiency. The number of plants per utility may reflect characteristics such as the commitment to nuclear power, the type of leadership, and/or the degree of bureaucratization. These factors influence the level of caution, the ability to solve problems, and the overall flexibility of the utility. It is easy enough for NRC inspectors and investigators to take into account this indicator, for the information is readily available. However, until additional research is done which helps us better understand what this indicator represents, it should not be used for diagnostic purposes.

d. Also influencing nuclear power plant performance are the changing signals that management receives about how well it is doing. Based on the work reported here, these signals come in two forms (1) information about safety lapses and problems recorded in the violations and LER data, and (2) information about the resources available from profit or debt to take corrective action. Management appears to pay attention to major violations before LERs because major violations are more severe and infrequent. After major violations, safety increases, but perhaps it is because plant use is curtailed while management investigates what has happened and takes corrective action. Efficiency, thus, suffers while management pays attention to these violations. Learning from the LERs is more gradual, but it does occur, particularly when resources are available. In the longer term, when resources are available learning from the LERs takes place. This research shows that improvement based on LERs is likely to come both in the areas of efficiency and safety. While caution in interpretation of results was urged in Chapter 4, further study of how improvements or learning takes place over time appears promising.

e. Two additional variables of promise are, therefore, the LERs and the financial indicators. They are particularly promising because of the role of time, the relatively long lags, and the ability of NRC and the utilities to take corrective action given these long lags. The present results suggest that it is two to three years after the occurrence of LERs that improvements in safety begin to appear. The availability of resources to make changes, at or around the time of the occurrence of the LERs appears in its own right to be a very important indicator of future safety performance. This insight confirms the simple but important proposition that utilities have to be able to afford safety, that safety costs money, and without adequate resources, it cannot be achieved. Again, it should be relatively easy for NRC investigators and enforcement officials to track LERs and financial performance in tandem and to consider the consequences of the interaction between these indicators. Information about the LERs already is available to investigators and enforcement officials. NRC now needs to maintain adequate records on utility financial performance (i.e., profit and leverage), so that this information also will be available and so that it can be considered along with the LER data.

8. Finally, this research suggests that the nuclear power plant organization and management model that shapes and guides future efforts must take into account that the plants are not simple machine-like organizations with well understood goals that can be pursued methodically through hierarchial command and control systems. Nuclear power plants are multi-purpose in nature. They have to balance competing claims such as efficiency and safety. They test the problem-solving and learning capacities of managers.

REFERENCES

Accident at TMI, Oversight Hearings, May 9-11, 15, 1979. U.S. Congress, House Committee on Interior and Insular Affairs, Subcommittee on Energy and the Environment.

Action Plan Developed as a Result of the TMI Accident. NUREG-0660, U.S. Nuclear Regulatory Commission, 1980.

Adler, P., and Clark, K. Behind the Learning Curve: A Sketch of the Learning Process. Working paper Stanford University Department of Industrial Engineering and Engineering Management, December 1987.

Angle, H., and A. Van de Ven in Van de Ven et. al. (Eds). "Suggestions for Managing the Innovation Journey," Research on the Management of Innovation. Cambridge, MS:Ballinger, 1989.

Argote, L. "The Persistence and Transfer of Learning in Industrial Settings," paper presented at ORSA/TIMS, St. Louis, October 1987.

Argyris, C. Personality and Organization. New York:Harper & Row, 1957.

Argyris, C., and D. Schon. Organizational Learning: A Theory of Action Perspective. Reading, MA:Addison-Wesley, 1978.

Arrow, K. Social Choice and Individual Values. New Haven, CT:Yale University Press, 2nd Edition, 1963.

Ashby, W. Design for a Brain. New York:McGraw-Hill, 1960.

Blake, "A Trend Toward Improvement in Capacity Factors," Nuclear News. May 1985.

Boegel, et al. Analysis of Japanese-U.S. Nuclear Power Plant Maintenance. NUREG/CR-3883, June 1985.

Bowman, E., and H. Kunreuther. "Post-Bhopal Behavior at a Chemical Company," Journal of Management Studies Vol. 25, No. 4, July 1988, pp. 387-402.

Bremer. "Economics of Planned Maintenance" and "Maintenance Success in Availability Trends." Electricite de France, April 1986.

Brookhaven National Laboratory, Presentation to the NRC Staff: Influence of Supervisor/Manager Factors on Performance Reliability. September 26, 1988.

Burns, T., and G. Stalker. The Management of Innovation. London:Tavistock, 1961.

Cameron, K. "Critical Questions in Assessing Organizational Effectiveness," Organizational Dynamics. Vol. 9, 1980, pp. 66-80.

Cameron, K., and D. Whetten. "Perceptions of Organizational Effectiveness over Organizational Life Cycles," Administrative Science Quarterly. Vol. 26, December 1981, pp. 525-544.

Campbell, J. "On the Nature of Organizational Effectiveness," In P. Goodman, J. Pennings, and Associates, New Perspectives on Organizational Effectiveness. San Francisco:Jossey-Bass, 1977.

Chakravarthy, B., and S. Kwun. "The Strategy Process: An Organizational Learning Perspective," Discussion paper, Strategic Management Research Center, University of Minnesota, August 1989.

Child, J. "Managerial and Organization Factors Associated with Company Performance--Part II: A Contingency Analysis," Journal of Management Studies. Vol. 12, 1975, pp. 12-27.

Child, J. "Organization: A Guide to Problems and Practice." New York:Harper & Row, 1977.

Chockie, A., J. Olson, and J. Thurber. "The Right Data for the Right Decision: Performance Indicators for Different Management and Regulatory Needs." Battelle HARC, September 10, 1988.

Clarification of TMI Action Plan Requirements. NUREG-0737, U.S. Nuclear Regulatory Commission, 1980.

Clarke, L. The Origins of Nuclear Power: A Case of Institutional Conflict, Social Problems. Vol 32, No. 5, June 1985, pp. 474-487.

Cohen, M. Conflict and Complexity: Goal Diversity and Organizational Search Effectiveness, The American Political Science Review. Vol 78, June 1984, pp. 435-451.

Cyert, R., and J. March. A Behavioral Theory of the Firm. Englewood Cliffs, NJ:Prentice-Hall, 1963.

Daft, R. Management. Chicago:The Dryden Press, 1988.

Del Sesto, S. "Uses of Knowledge and Values in Technical Controversies: The Case of Nuclear Reactor Safety, Social Studies of Science. Vol. 13, 1983, pp. 395-416.

Downs, A. Inside Bureaucracy. Boston:Little, Brown, 1967.

Drazin, R., and A. Van de Ven. "Alternative Forms of Fit in Contingency Theory," Administrative Science Quarterly. Vol. 30, No. 4. December 1985, pp. 514-539.

Duncan, R., and A. Weiss. "Organizational Learning: Implications for Organizational Design," Research in Organizational Behavior. 1979, Vol. 1, pp. 75-123.

Dutton, J., A. Thomas, and J. Butler. "The History of Progress Functions as a Managerial Technology," Business History Review. 1984, pp. 204-233.

Eagan, S. "To Err is Human Factors," Technological Review. Feb-Mar 1982, pp. 23-29.

Ellis, R. and M. Zimmerman. "What Happened to Nuclear Power: A Discrete Choice Model of Technology Adoption," Review of Economics and Statistics. Vol. 65, May, 1983, pp. 234-242.

Elster, J. Explaining Technological Change. Cambridge,MO: Cambridge University Press, 1983.

England, R. "Disaster-Prone Technologies, Environmental Risks, and Profit Maximization." KCKLOS, Vol. 41, 1988, pp. 379-395.

Eschbach, E., and C. Schuller. "Small Nuclear Power Reactors: An Assessment of Their Commercial Potential." Battelle Northwest Laboratory, September 1983.

Etzioni, A. Modern Organizations. Englewood Cliffs, NJ:Prentice-Hall, 1964.

Fayol, H. General and Industrial Management. London:Pitman, 1949.

Fiol, C., and M. Lyles. "Organizational Learning," The Academy of Management Review. Vol. 10, No. 4. October 1985, pp. 803-813.

Fishoff, B., S. Lichtenstein, P. Slovic, S. Derby, and R. Keeney. Acceptable Risk. Cambridge:Cambridge University Press, 1981.

Greenberg, L. "The Application of Accident-Experience Learning Curves to the Study of Occupational Accidents in the American Petroleum Industry." New York:New York University, Ph.D Dissertation, 1969.

Greenberg, L. "Measurement of the Work-Accident Experience in the American Petroleum Industry," American Society of Safety Engineers. Vol. 15, No. 2, 1970, pp. 11-13.

Greenberg, L. "Why the Mine Injury is out of Focus," Mining Engineering. Vol. 23, No. 3, 1971, pp. 51-53.

Haber, S. "Proceedings from the Organization and Management Research Agenda Workshop." Brookhaven National Laboratory, February 1989.

Haber, S., et al. "An Organizational Model of a Nuclear Power Plant." Brookhaven, April 27, 1988.

Hall, Richard R. "Professionalization and Bureaucratization." American Sociological Review. Vol 33, 1968, pp. 92-104.

Hammond, K. and J. Mumpower. "Fundamental Obstacles to the Use of Scientific Information in Public Policymaking," Technological Forecasting and Social Change. Vol. 24, 1983, pp. 287-297.

Hendrickson P., M. Muellen, and D. Carr. Financial Qualifications Review of Applicants for Nuclear Power Plant Construction Permits. NUREG/CR-5218, September 1988.

Hoover, K. The Elements of Social Scientific Thinking. New York, NY:St. Martin's Press, 1976.

Human Synergistics, Organizational Culture Inventory. 1987.

Interoffice Task Group on Performance Indicators, Performance Indicator Program Plan for Nuclear Power Plants. September 1986.

Investigation into the March 28 1979 TMI Accident. NUREG-0600, U.S. Nuclear Regulatory Commission, Office of Inspection and Enforcement, 1979.

Janis, I. Groupthink: Psychological Studies of Policy Decisions and Fiascoes. Boston, MA:Houghton Mifflin Co. 2nd Edition, 1982.

Johnston, J. "Econometric Methods," New York:McGraw-Hill 3rd Edition, 1984.

Kemeny, J. The Need for a Change: The Legacy of TMI. Report of the President's Commission on the Accident at Three Mile Island. Washington, D.C. Government Printing Office, 1979.

Kim, Y. Justification of Policy Error Correction: A Case Study of Error Correction in the Three Mile Island Nuclear Power Plant Accident. Ph.D. Dissertation, Indiana University, 1982.

Komaki, et al. "Development of an Operant-Based Taxonomy and Observational Index of Supervisory Behavior," Journal of Applied Psychology. Vol. 71, No. 2, 1986.

Labovitz, S., and R. Hagedorn. Introduction to Social Research. New York:McGraw-Hill Company, 1976.

Landau, M. "On the Concept of a Self-Correcting Organization," Public Administration Review. Vol. 33, November/December 1973, pp. 532-42.

Lawrence, P. and J. Lorsch. Organization and Environment. Cambridge, MA:Harvard Graduate School of Business Administration, 1967.

Lois, E., J. Wreathall, and J. Fragola. "Issues Associated with the Development of Nuclear Power Plant 'Program Effectiveness' Indicators for Regulatory Use." U.S. Nuclear Regulatory Commission, 1988.

March, J., and J. Olsen. Ambiguity and Choice in Organizations. Bergen:Universitetsforlaget, 1976.

March, J., and Shapira, Z. Managerial Perspectives on Risk and Risk Taking, Management Science. Volume 33, No. 11, 1987, pp. 1404-1418.

Marcus, A. "Implementing Externally Induced Innovations: A Comparison of Rule-bound and Autonomous Approaches," Academy of Management Journal. Vol. 31, No. 2, June 1988a, pp. 235-256.

Marcus, A. "Risk, Uncertainty and Scientific Judgement," Minerva. Vol. 26, No. 2, Summer 1988b, pp. 138-152.

Marcus, A., and I. Fox. "Lessons Learned About Communicating Safety Related Concerns to Industry." Carlson School of Management, November 1988.

Marcus, A., and R. Goodman. "Compliance and Performance: Toward a Contingency Theory," Research in Corporate Social Performance and Policy. Vol. 8, 1986, pp. 193-221.

Marcus, A. and R. Osborn. Safety Review at Nuclear Power Plants: A Review Assessment. Seattle, WA:Battelle Human Affairs Research Centers, prepared for U.S. Nuclear Regulatory Commission, May 1984.

Matsuda, Y. "Nuclear Power in Japan: Present and the Future," Journal of Japanese Trade and Industry. Vol. 6, 1984, pp. 12-26.

McGuire, J., A. Sundgren, and T. Schneeweis. Academy of Management Journal. Vol 31, No. 4, 1988, pp. 854-877.

Megginson, L., D. Mosley, and P. Pietri, Jr., Management: Concepts and Applications. New York:Harper & Row Publishers, 1983.

Meshkati, M. "An Integrative Model for Designing Reliable Technological Organizations: The Role of Cultural Variables." paper presented at The World Bank Workshop on Safety Control and Risk Management in Large-Scale Technological Operations, Washington, D.C., October 1988.

Miles, R. Coffin Nails and Corporate Strategies. Englewood Cliffs, NJ:Prentice-Hall, 1982.

Miller, D., and P. Friesen. Organizations: A Quantum View. Englewood Cliffs, NJ:Prentice-Hall, 1984.

Miller, D., and P. Friesen. "Archetypes of Strategy Formulation," Management Science. Vol. 24, 1978, pp 921-933.

Miller, D., and H. Mintzberg. "The Case for Configuration," in G. Moran (ed.) Beyond Method: Strategies for Social Research. Beverly Hills, CA:Sage, 1983, pp. 57-73

Mintzberg, H. "The Effective Organization Forces and Forms." McGill University, Montreal, December 1988.

Mintzberg, H. The Structuring of Organizations. Englewood Cliffs, NJ:Prentice-Hall, 1979.

Mitroff, I. "Crisis Management: Cutting Through the Confusion." Sloan Management Review, Winter 1988, pp. 15-20.

Mitroff, I. "Cultural Barriers to Learning: Profiles of Crisis Prone Organizations," Paper presented at the Industrial Crisis Conference, NY, 1988.

Mitroff, I., T. Pauchant, and P. Shrivastava. "The Structure of Man-made Organizational Crises," Technological Forecasting and Social Change. Vol. 33, pp. 83-107.

Morey N. and B. Huey. Human Factors Research and Nuclear Safety. Washington D.C.:National Academy Press, 1988, pp.80-88.

Morgan, G., Images of Organization. Newbury Park, CA:Sage 1986.

Nachmias, D., and C. Nachimas, Research Methods in the Social Sciences. New York, NY:St. Martin's Press, 1976.

Nichols, E. and A. Wildavsky. "Regulating by the Numbers: Probabilistic Risk Assessment and Nuclear Power," Evaluation Review. Vol.12, No. 5, 1988, pp. 528-545.

Nuclear Accident and Recovery at Three Mile Island: A Special Investigation. Investigation Report, Senate Subcommittee on Nuclear Regulation, July 1980.

Olson, J., et. al. Development of Programmatic Performance Indicators. Draft NUREG/CR-5241, September 1988.

Olson, J., et. al. An Initial Empirical Analysis of Nuclear Power Plant Organization and Its Effect on Safety Performance. NUREG/CR-3737. November 1984.

Olson, J., et al. Objective Indicators of Organizational Performance of Nuclear Power Plants. NUREG/CR-4378, January 1986.

Osborn, R., J. Hunt and L. Jauch. Organization Theory. New York:John Wiley and Sons, 1980.

Osborn, R., and D. Jackson. "Leaders, Riverboat Gamblers, or Purposeful Unintended Consequences in the Management of Complex, Dangerous Technologies," Academy of Management Journal. Vol. 31, No. 4, December 1988, pp. 924-947.

Osborn, R., et al. Organizational Analysis and Safety for Utilities with Nuclear Power Plants. NUREG/CR-3215, 2 volumes, August 1983.

Pauchant, T., and I. Mitroff. "Crisis Prone Versus Crisis Avoiding Organizations: Is Your Company's Culture its Own Worst Enemy in Creating Crises?" Industrial Crisis Quarterly. Vol. 2, 1988, pp. 53-63.

Perrow, C. Normal Accidents: Living with High-Risk Technologies. New York:Basic Books, Inc. 1984.

Perrow, C. "The Organizational Context of Human Factors Engineering," Administrative Science Quarterly. Vol 28, 1983, pp. 521-541.

Poole, M., and A. Van de Ven. "Ways to Address Paradox in Management and Organization Theories." Strategic Management Research Center, University of Minnesota, October 1988.

Porter, M. Competitive Advantage: Creating and Sustaining Superior Performance. New York:The Free Press, 1980.

Price, J. Organizational Effectiveness. Homewood, IL:Irwin, 1968.

Quinn, R., and K. Cameron. "Organizational Life Cycles and Shifting Criteria of Effectiveness," Management Science. Vol. 9, 1983, pp. 33-51.

Quinn, R., and Cameron, K. (Eds) Paradox and Transformation: Toward a Theory of Change in Organization and Management. Cambridge, MA:Ballinger, 1988.

Rasmussen, J. "Coping Safely with Complex Systems." invited paper for American Association for Advancement of Science Annual Meeting, Boston, February 11-15, 1988.

Rasmussen, J., K. Duncan, and J. Leplat. New Technology and Human Error. New York:John Wiley and Sons, 1987.

Reason, "Resident Pathogens and Risk Management." draft of paper presented for World Bank Workshop on Safety Control and Risk Management, October 18-20, 1988.

Ryan, T. "Human Performance Measurement:Issues and Challenges." Office of Nuclear Regulatory Research, September 10, 1988.

Scott, W. Organizations, Rational, Natural, and Open Systems. Englewood Cliffs, NJ:Prentice-Hall, 1987.

Shrivastava, P., I. Mitroff, D. Miller, and A. Miglani. "Understanding Industrial Crisis," Journal of Management Studies. Vol. 25 No. 4, July 1988, pp. 285-304.

Simon, H. "On the Concept of Organizational Goal," in H.I. Ansoff Business Strategy. New York, NY:Penguin Books, 1977 ed., pp. 240-262.

Sommers, P. "A Guide to Literature Relevant to the Organization and Administration of Nuclear Power Plants." Washington, D.C., Battelle Human Affairs Research Centers, February 1984.

Staff Studies: Nuclear Accident and Recovery at Three Mile Island - A Special Investigation. U.S. Congress, Senate Committee on Environment and Public Works, Subcommittee on Nuclear Regulation, 1980.

Starbuck, W. and F. Milliken. Challenger: Fine-Tuning the Odds Until Something Breaks, Journal of Management Studies. Vol 25 No. 4, July 1988, pp. 319-340.

Steers, R. "Problems in the Measurement of Organizational Effectiveness," Administrative Science Quarterly. Vol. 20, December 1975, pp. 546-58.

Steers, R. Organizational Effectiveness: A Behavioral View. Santa Monica, CA:Goodyear, 1977.

Steiner, G., and J. Steiner. "The Union Carbide Corporation and Bhopal," Business, Government, and Society: A Managerial Perspective. New York:Random House, 1988, pp. 303-316.

Stello, Performance Indicators. October 28, 1986.

Taylor, "Kewaunee's Plant Management Practices Set An Example," Nuclear News. May 1985.

Taylor, F. Principles of Scientific Management. New York:Harper & Row, 1911.

Three Mile Island: A Report to the Commissioners and to the Public, Volumes I and II, Parts 1, 2, and 3. NUREG/CR 1250, U.S. Nuclear Regulatory Commission. M. Rogovin, Director, Nuclear Regulatory Commission Special Inquiry Group.

TMI-2 Lessons Learned Task Force Final Report. NUREG-0585, U.S. Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation.

Thurber, J. "A Description of Maintenance Initiatives Practices and Regulations.... PNL, August 12, 1988.

Thurber, J., and B. Melber, C. Geisendorfer, and R. Vallario. "Evaluation and Proposed Improvements to Effectiveness of U.S. Nuclear Regulatory Commission Generic Communications." Prepared for U.S. Nuclear Regulatory Commission. Battelle Human Affairs Research Centers, Pacific Northwest Laboratory, January 1988.

Van de Ven, A. Central Problems in the Management of Innovation, Management Science. Vol 32, No. 5, 1986, pp. 590-607.

Van de Ven, A., B. Dornblaser, and T. Lin. "The Temporal Development of Innovation Outcomes, Learning and Action Loops." Strategic Management Research Center, University of Minnesota, January 1989.

Van de Ven, A., H. Angle, and M. Poole. (Eds) Research on the Management of Innovation. Cambridge, MA: Ballinger, 1989.

Van de Ven, A., and M. Poole. "Paradoxical Requirements for a Theory of Organizational Change," Paradox and Transformation: Toward a Theory of Change in Organization and Management. Cambridge, MA:Ballinger Publishing Co., 1988, pp. 19-80.

Van de Ven, A., and Ferry. "Measuring and Assessing Organizations." New York:John Wiley & Sons, 1980.

Van de Ven, A. and R. Drazin. "The Concept of Fit in Contingency Theory," Research in Organizational Behavior. Vol. 7, 1985, pp. 333-365.

Vinokur, A. "Review and Theoretical Analysis of the Effects of Group Processes Upon Individuals and Group Decision Involving Risk," Psychological Bulletin. Vol. 78, October 1971, pp. 231-241.

Weber, M. The Theory of Social and Economic Organization. New York:MacMillan, 1947.

Weick, K. "Organizational Culture and High Reliability," California Management Review. Vol. 29, No. 2, Winter 1987, pp. 112-127.

Weick, K. "Enacted Sensemaking in Crisis Situations," Journal of Management Studies. Vol 25, No. 4, July 1988, pp. 305-317.

Weick, K. "Technology as Equivoque: Sense-making in New Technologies," paper presented at the Conference on Technology. Carnegie-Mellon University, August 28-30, 1988.

Whyte, G. "Groupthink Reconsidered," The Academy of Management Review. Vol. 14, No. 1, January 1989. pp. 40-56.

Wiener, N. Cybernetics. Cambridge, MA:MIT Press, 1961.

Wildavsky, A. Searching for Safety. New Brunswick:Transaction Press, 1988, pp. 125-147.

Woodward, J. Industrial Organization:Theory and Practice. London:Oxford University Press, 1965.

Wreathall, et. al. (SAIC), Framework of Analysis for the Identification and Selection of Programmatic Performance Indicators. May 1988.

Yelle, L. "The Learning Curve: Historical Review and Comprehensive Survey," Decision Sciences. Vol. 10, 1979. pp. 302-328.

Zucker, L. "Institutional Theories of Organization," Annual Review of Sociology. Vol. 13, 1987, pp. 443-464.

APPENDIX A

THREE PERSPECTIVES ON EMERGENT PROCESS

(1) An Enactment Perspective

Perhaps the most eloquent statement of the enactment perspective is by Karl Weick (1988a, 1988b). His work suggests that it is important to understand how individuals perceive and act on their perceptions. Fundamental to this approach is the intervention of attention and understanding between external conditions and individual responses. One does not move from (a) situation to (b) seeing to (c) understanding to (d) acting as if some natural laws were in effect. In a complex setting, for instance, an operator may not "see" a safety threat because the clues to this threat are consistent with his understanding of a small variation in normal operations.

Weick (1988a) views enactment as both a process and a product. Portions of experience are singled out as relevant. Action within this context tends to confirm preconceptions. An enacted environment often has two faces -- a public and a private face. The public face is a causal map that is visible to observers other than the actor while a private one is not.

Weick (1988a) uses the enactment perspective to make some interesting suggestions concerning action and inaction in high risk technologies. The analysis turns to asking how individual actions can "cause" an industrial crisis. Essentially he describes a series of cycles of action and cognition tied to confirmation of preconceptions to demonstrate escalation or mitigation of the initial triggering event. Part of the analysis also shows how different initial starting points yield escalation or mitigation. For instance, an initial starting point of Bhopal was that the plant was not very important and that secrecy was important in the eyes of executives. Plant personnel acted out these expectations and in doing so made the consequences of the accident much worse. He suggests that the real lesson is that hazards are not inherent but enacted. Thus, crises are potentially more controllable than many believe, but theorists must understand more completely the enactment process and the role of commitment to isolate blind spots and escalation areas.

Without going into the details of the enactment approach, two important points of departure for the current project should be noted. One, the enactment view postulates that cognition lies in the path of actions such that the perceptions of participants are a critical starting point for analyzing organizations. Two, at the macro level it is important to recognize the informal aspects of the organization and the manner in which individuals view the administrative system. For instance, very detailed analyses are needed of precisely how individuals within the utilities envision

the structure and comprehend their relation to it. Do individuals see the formal structure as a constraint, a license to act, and/or interpret some aspects as an irrelevant appendage and only useful to others.

In a very recent paper Weick (1988b) further extends the enactment perspective to dangerous, process technologies. Individuals face the novel problem of how to recover from failures that are hard to understand. The failures may be difficult to understand because (1) little is visible (2) much is transient and (3) interactions within the technology may be modeled in quite different ways.

Weick's argument is framed around different types of events. He discusses stochastic events, continuous events, and abstract events. For stochastic events he asks if individuals will perceive problems and the pattern of the "problems". Important events are randomly occurring and unpredictable. Uncertainties appear to be permanent rather than transient. An anomaly may not be understood and can recur; if repeated, there is some chance for learning but only if the organization operates in an experimental mode. Yet, operating in such a loose fashion may be dangerous in some technologies such as nuclear. Stochastic events present problems because they are a moving target for learning; they change faster than people can accumulate knowledge about them. Continuous processes impose their imperative of reliability. He distinguishes between efficiency (a ratio of inputs to outputs) and reliability (continuity of the process). He suggests that it is more important to keep the process going than to economize. Yet, the two imperatives might be confused. Where economizing calls for limited job scopes and responsibilities, reliability requires higher task responsibility, the capability to deal comfortably with abstraction, and the ability to develop a deep appreciation for qualitatively greater levels of interdependence. Weick notes that the combination of stochastic events and continuous ones yields (a) increased cognitive requirements (b) increased electronic complexity, (c) dense interdependence and (d) increased incidence of unexpected outcomes. Abstract events rest on the fact that much of the work has disappeared into machines, suggesting that operators and managers need abilities in inference, imagination, integration, problem solving and developing mental maps to understand and solve problems. Error occurs when the individual strays from the prescribed course of action while a mistake occurs via misconception, misidentification or misunderstanding, for example, diagnosing a design flaw where individual indicators inhibit the ability to recognize an underlying pattern of causation. Since much is not visible, there are "two technologies operating" -- the physical and that in the minds of operators/managers. These two may become decoupled. The need is to shift attention to the social system -- members' use of rules and resources in interaction. Both formal structures and alterations by individuals must be considered. The technology thus interacts with human emotion and cognition to produce potentially

damaging consequences. For instance, technological factors ask for broader interpretation and theorizing, while high stress situations tend to narrow cognition, resulting in conventional actions.

The enactment analysis could easily be extended to note that multiple, partially conflicting criteria for performance are evident in complex technologies and that these criteria carry with them different implied desirable conditions and cause-effect relationships. Cohen's (1984) review of the literature on conflicting organizational goals implied that informal mechanisms may be used to partially reconcile conflicting or diverse goals.

Deep within the plant we need to closely examine how the demands of the technology become seen, understood and translated into action. The ability of individuals to both conform to specifications and liberate themselves to improve safety needs to be carefully investigated. Here one needs to go beyond functional specification and investigate the intricate interplay among unit members, supervisors, and important external units. For instance, Eagan (1982) argued that the engineering world within the plant was one of the "mind" while operators dealt with the feedback from the plant or the "hand". Weick's analysis now alerts us to the importance of examining the minds of the operators and how their mental models (what they see and what they understand) can be linked to the models envisioned by engineers. It is quite possible that in operating a nuclear plant, particularly in an emergency, the ability to link engineers and operators with a common mental model or through a series of shared mental models is particularly critical, but very difficult. More extensive coordination mechanisms may well help participants share more sophisticated and elaborate mental models, which may allow them to both see and understand more.

(2) <u>An Institutional Perspective</u>

As Shrivastava, Mitroff, Miller and Miglani (1988) suggest, crises such as Bhopal, the Tylenol poisoning and the explosion of the space shuttle are also organizational and inter-organizational phenomena. They are caused by human, organizational communication, and technical failures. The analysis of institutional processes attempts to understand the evolving actions of organizations in their interaction with others. Institutional perspectives of emergent systems often concentrate on the power relationships that balance competing interests within the framework of an evolving ideology. Just as cognition is interjected between stimulus and response for individuals, so is ideology interjected between events and responses for corporations. The institutional perspective is important to incorporate into this discussion because institutional relationships may have an important impact on the ability and willingness of utilities to adopt innovative programs. (for a

recent review of the institutional perspective literature see Zucker, 1987).

The process of responding to disasters has been studied from the institutional perspective by Bowman and Kunreuther (1988). In an extensive case study of firms' reaction to Bhopal they observed the following:

1. Managers immediately perceived the disaster to influence possible safety problems in the entire chemical industry and their specific company.

2. While most jobs and behaviors did not change, those of some safety specialists did and some executives were appointed to study teams (task forces) to study the safeness of company operations.

3. The safety task-force conducted a company survey, analyzed and reduced safety problems to a chosen few "worst-case" scenarios for subsequent evaluation.

4. The safety task force visited a few worst case sites, where it conducted plant tours, inspected facilities, and conducted training sessions to standardize safety procedures across plants.

5. The task force developed a set of recommendations for improving safeness of worst-case issues, distributed preliminary drafts of recommendations to operating managers, who, in turn, suggested modifications. The modifications made tended to focus on reducing or modifying the most costly safety policy guidelines.

6. The task force completed its work by developing 24 principles for implementation. Implementation of modified recommendations was delegated to managers of different plants.

While this may appear to be a straightforward response to the disaster, Bowman and Kunreuther (1988) draw attention to some important implications for understanding the process of responses to accidents. These include:

1. While the crisis triggers attention, the focus of attention is on proximate causes not more fundamental causal factors or chronic safety issues. In fact attention was diverted away from dealing with chronic problems such that immediate short-term events drove out attention to potentially more important chronic deficiencies.

2. Responsibility for safety and corrective action was isolated and localized to specialized segments of the companies -- thereby allowing "business as usual" throughout the rest of the organization.

3. The analyses of the task forces was retrospective and focused on issues of accountability and responsibility for current

practices. It did not attempt to explore "best" responses for improving safety.

4. While the increased attention triggered centralized hierarchical control and speedy implementation of solutions, examination of more fundamental underlying problems using search, exploration of alternatives and reconciliation of inconsistencies was missing.

5. The process did facilitate coordination and communication across different parts of the organization by "opening" organizational boundaries that were previously closed. However, solutions were often fitted into preexisting beliefs and preexisting definitions of problems.

6. Planners were separated from doers with little assurance that planed activities would be sustained after initial implementation.

In other words, simple rules of thumb were used to make safety problems easier to resolve while the search for problems was limited to worst-case scenarios. Conflicts were minimized by the process and ideas, activities and knowledge existing before the accident were used to "solve" the safety threats made apparent by the disaster. No new conceptions of safety nor fundamental changes in management and organization were made.

Their analyses suggests the following propositions might be examined in the nuclear power setting:

P24. Attention to safety issues may be misdirected toward immediately solvable, minor conditions and away from more fundamental issues, particularly in more centralized utilities.

P25. In the process of isolating safety problems there is a tendency to ignore the broader objective data and merely incorporate existing problems and solutions.

P26. Solutions may drive the search problems and new problems may be redefined to match those already being addressed.

P27. Fundamental change in management and organizational practices will not be seen in responses to the accidents of others.

In sum, reaction to prior performance deficiencies by related corporations may trigger improvement by others, yet it is not clear that this improvement is based on management attempts to make the situation "look" better or whether substantive changes that improve safety are instituted. In this vein it is important to reiterate the findings of Starbuck and Milliken (1988). They suggest that actions and processes emerging from past successes and failures may be poorly understood. With a record of apparent success and conflicting understandings within the system, managers seeking efficiency and engineers seeking greater technical elegance may

"fine tune the odds" by embarking upon changes that improve efficiency and technical elegance but at the cost of cumulative, unrecognized negative consequences for safety.

(3) Organizational Learning Perspective

Institutional process approaches and the enactment perspective partially build upon the growing literature emphasizing organizational learning. In one respect the learning approach predates most organizational analyses, as engineers have logically expected to see declining costs as experience with a technology increased. Recently somewhat more elaborate models of organizational learning have emerged from the literature. These are used in Chapter 4 to develop some testable hypotheses concerning events (e.g., LERs and major violations) and subsequent improvements in plant safety. Here we merely characterize this emerging literature and point out its potential for helping to understand emerging dynamics in the safety of nuclear power plants.

We may begin by noting the historical popularity of the simple learning curve or "progress function." As experience increases costs should decline (improvement in efficiency) and the number of mistakes should slowly be reduced. The term "curve" is used because initial improvements are dramatic while additional experience provides successively less improvement. In a review article, Dutton, Thomas and Butler (1985) chart the historical development of the progress function (learning curve in industrial settings), first in academic writings then in application. They argue that complexities in application and a separation of academic and applied studies have restricted refinement of the concept. When not refined, applied studies showed it not to be operating as academics expected. They call for more complex learning models.

One such model by Adler and Clark (1987) charts a more complex learning curve by focusing on the human aspects of learning within an industrial high technology setting, They distinguish between first-order learning and second-order learning. First-order learning is knowledge accumulation via doing, and appears based on repetition. Second-order learning is an accumulation of knowledge that transforms the goals of the process and/or changes technological components such as equipment, managerial action and/or human capital.

An even more complex and realistic model focusing on such processes is provided by Angle and Van de Ven (1989). Angle and Van de Ven outline a complex process model that includes several potential discontinuities rather than a smooth line of progress from inception to ultimate deployment of a new idea or solution. At different phases of the process managers face organizational learning problems. While this is quite a complex model there are several important potential lessons for the analysis of safety. First, they posit that there may be "vicious cycles" and that

ambiguity of cause-effect relationships and multiple criteria may be compounded by "superstitious learning". As in the Starbuck and Milliken (1988) discussion of "fine-tuning the odds," it is not at all clear that in complex technical situations with ambiguous criteria, knowledgeable personnel will adequately frame their experience and draw appropriate lessons from their experience. Angle and Van de Ven posit a number of other interesting and potentially useful sets of relationships among predictors and criteria under conditions of ambiguity in criteria (multiple and comparatively uncorrelated dimensions of safeness) and uncertainty concerning cause-effect relationships. For instance, they argue that there are likely to be comparatively separate success and failure cycles where accurate depiction of the experience is unlikely. Consider the following cycle. Complex external pressures may trigger a course of action that may be deemed problematical yielding the perception of failure and uncertainty concerning problem definition and resolution. This in turn triggers outside intervention and a struggle for control. This process is escalated because of superstitious learning and attributional problems (problems external while success internal). Conversely, consider a benefit cycle where embarking upon an apparent successful course of action triggers positive but inaccurate attributions. In this cycle positive attributions of the participants' actions, skill, and insight lead outsiders to increase the delegation of discretion to project participants. Again the cycle continues. However even the positive cycle may lead to disaster because both participants and outsiders are unable to accurately depict the complex causal relations involved in a fixed definition of success. It is important to note that both the causal maps of outsiders and participants as well as the criteria for evaluation shift to match the limitations and learning problems articulated in the model.

Advanced learning (e.g., recognition of the cycles described above, coupled with a more realistic picture of what is actually the underlying series of causal mechanisms) may be comparatively rare in mechanistic systems with complex continuous, technologies because of the predominance of efficiency over understanding. Without advanced organizational learning, or its equivalent, the system may be subject to a number of accelerating dysfunctional cycles, punctuated by a crisis. (cf. Marcus, 1988a). Conversely, a more positive beneficial cycle might be found where continuously higher performance is recorded until some state condition changes. However, without advanced learning, it may be difficult for the plant to recreate the beneficial cycle under new state conditions. One important place to start such investigations is to plot the responses of nuclear utilities to events that question their current practices (e.g., major events) and the more routine discovery of minor inconsistencies between desired conditions and actual conditions (e.g., minor LERs).

Summary of Emergent Processes

In summary, an emergent process perspective alerts us to the folly of attempting to deduce all important linkages among management and organizational factors in complex socio-technical systems. It is important to study these entities in-depth to begin plotting how individuals make them work, how institutional factors model the range of options open to them, and how they learn to balance the myriad of competing goals and interests inherent in safely operating a nuclear power plant.

APPENDIX B

SUMMARY OF RESPONSES FROM NRC INTERVIEWS ABOUT MANAGEMENT AND ORGANIZATION AND SAFETY PERFORMANCE OF NUCLEAR POWER PLANTS

<u>What are the best safety performance indicators of nuclear power plants?</u>

Most respondents offered slightly different definitions of nuclear power plant safety. There was little agreement on an ideal list of safety performance indicators. They were supportive of the effort to establish safety performance indicators, but felt that other factors should be taken into account beyond trends in quantitative indicators.

There was general support for the six current NRC performance indicators as one way to judge the safety performance of NPPs: unplanned scrams, forced outages, outage rate, engineered safety system actuations, safety system failures, and significant events. Respondents felt that other factors beyond PIs must be taken into account when judging safety performance of plants, such as SALPs, human errors, NRR staff judgment, NRC regional staff judgment, judgment of NRC regional administrators, and NRC senior management judgment.

<u>What are the best indicators of NPP management and organization performance?</u>

Respondents listed a variety of management and performance indicators that are important for NRC to monitor at NPPs. They often found it difficult to empirically define the concepts that they felt were important. Often they would rely on "you know it when you see it" conclusions about a specific factor. There was difficulty in defining what they meant by "good," "solid," "outstanding," "well," and other adjectives. With these caveats in mind, the following summary comments about NPP management and organization were made by the respondents.

1. A well managed NPP is one in which everyone is well aware of the goals and objectives of the organization (e.g., Duke Power has an informal survey of employees each month concerning the goals and objectives of the organization, in order to determine effectiveness of the management).

2. There is a time lag between management action and a change in performance indicators. Management effectiveness may go down well before one sees a change in the performance indicators. With good management, there is a causal link between their action and a change in the performance indicators.

3. Positive attitudes, good morale, and a highly motivated NPP work force is a sign of good management. The primary suggestion for measuring these organizational climate and culture variables was surveys and systematic observation by NRC staff.

4. A well managed plant has good discipline.

5. Face to face management involvement with the work force and management involvement in problem solving is important to a safe plant.

6. Good two-way communications between managers and employees is essential. Good cross functional communication within the NPP, and good communication between corporate and NPP is important to safety performance.

7. A feeling of involvement by the work force, a bottoms up problem solving culture in the NPP is good. Is the NPP a problem solving culture? How aggressive are the managers and work force in trying to solve problems and improve? How effective is the NPP in taking corrective action? Do problems keep recurring? Do they do extensive root cause analysis?

8. Low turnover rate of the work force (but this cuts both ways, be careful) is essential to good safety performance.

9. Use of performance indicators by management. How do managers and others monitor and use performance indicators? How comprehensive are the performance indicators? How do the managers feed NRC and industry wide data into their decision making? Does the NPP have an effective management information system in place and working?

10. What kind of accountability exists in the organization? Well managed NPPs have effective systems of accountability, recognition and rewards. Good job descriptions defining roles and responsibilities are an important element in judging the quality of management and organization. Good performance standards, performance monitoring and feedback to management is another good measure of management.

11. Working conditions and compensation are important measures of management and organization.

12. Clear policies and procedures of the organization are important to good safety performance.

13. Well educated and trained personnel are essential for a safe plant. Personnel qualifications, training and development are good measures of this.

14. A well run decision making system in crisis and under normal operating conditions will result in a safe plant.

<u>Of all of the measures of NPP management and organization that you have mentioned, what are the five most important (useful) indicators for the NRC?</u>

Taking into account the limited number of respondents, there was some consensus around the following five M and O variables (with respondent definitions and suggested empirical measures of the concepts):

1. Leadership. Definitions: the capacity to effectively command and direct the NPP; the ability of management to set goals and objectives, communicate them, and get the work force to accept and act on them. Suggested measures: "You know it when you see it."; attitudes of employees about management; knowledge of management's goals and objectives throughout the organization.

2. Accountability. Definition: managers and individuals in the NPP work force are answerable for their performance; meeting goals and objectives and performance standards; effective discipline and feedback regarding performance of plant and individuals. Suggested measures: existence of effective performance standards and system; effective performance monitoring, feedback, recognition, incentives, and rewards/punishments.

3. Performance indicators. Definitions: systematic collection and use of variables that measure and trend NPP performance; comprehensive awareness and use of PIs by management and employees throughout the NPP; the number of PIs collected and monitored. Suggested measures: evidence of use of NRC, industry, and plant PIs.

4. Communication. Definitions: clear expression and understanding within the organization; management speaking frequently face to face within the organization; good transmission of goals and objectives vertically and horizontally in the NPP; good bottoms up communication. Suggested measures: evidence that communication has an impact on action to solve problems and improve NPP performance.

5. Problem solving culture. Definitions: a social and organizational structure that rewards improvement and problem solving; structural integration of managers and work force into a problem solving organization. Suggested measures: ability to solve problems (e.g., low number of recurring problems).

APPENDIX C

A SUMMARY OF EMPIRICAL AND OTHER STUDIES RELATING MANAGEMENT AND ORGANIZATION TO SAFETY

Prepared by Alfred A. Marcus

Blake, "A Trend Toward Improvement in Capacity Factors," Nuclear News, May 1985 -

Shows which plants had highest capacity factors in 1982-84. Prairie Island in Minnesota was best. Detects a trend toward better performance and interviews managers at plants with better records.

Boegel et. al. Analysis of Japanese-U.S. Nuclear Power Plant Maintenance, June 1985 NUREG/CR-3883.

An analysis of the Japanese nuclear power program. Japanese plants outperform U.S. plants with respect to manual shutdowns, manual scrams, automatic scrams, and reduced loads, and their mean time between events, even adjusted for differences in plant availability, was approximately 10 times greater than in the U.S. The data compare 1981-83. Besides preventive maintenance, the authors engage in a thorough discussion of Japanese organization and management practices including the regulatory context, utility relations with vendors and contractors, labor relations, organization and structure, etc. They attribute Japanese successes to some of the following factors:

the group orientation of Japanese society

rotation of teams of workers who are cross-trained for a variety of jobs

labor relations

the use of subcontractors

close and stable relations between utilities, vendors, and subcontractors.

This report does not do standard correlation or regression analysis. However, it has useful descriptive statistics from 1981-83 comparing U.S. and Japanese plants on such items as availability, capacity, average number of events for PWRs and BWRs, mean time between events, etc.

Bremer, "Economics of Planned Maintenance" and "Maintenance Success in Availability Trends," Electricite de France, April 1986.

Two documents that describe maintenance management practices in France. They first discuss French performance indicators - plant availability, number of forced outages, components reliability, and radiation exposure, then they show how the French emphasize economics, i.e. costs of programs, a consideration absent from American thinking ("a balance between the benefits of modification and the subsequent indirect costs resulting from lost energy has always to be maintained"). The French achieve cost reductions or efficiency via standardization, centralization, planning, and the experience feedback system. "The French philosophy is to build less expensive plants reaching a satisfactory availability factor (83 per cent or more) at a cost of 2 to 5 per cent of the total investment over 5 years, and this with help of selected modifications applied to the <u>weak points</u> only and not to the <u>systems</u>." The French approach works as follows. Most countries concentrate on high quality design with high investment costs resulting in an excellent and reliable end product. The French accept the risk of some failures during the first five years of operation. "The maintenance costs during the first five years of commercial operation represent between 2 and 4 percent of the total investment costs. The modifications necessary to increase equipment reliability represent 1 percent of these costs. So the French policy is to build nuclear power plants at a lower cost reaching a high availability factor, providing an overcost of 2 to 5 percent integrated over 5 years and this with the help of carefully selected modifications to correct the weak points only and not the systems."

Brookhaven National Laboratory, <u>Presentation to the NRC Staff: Influence of Supervisor/Manager Factors on Performance Reliability</u>, September 26, 1988.

Overheads from a presentation by BNL on descriptive model of human organization of a NPP, identification of key supervisory/management functions and processes related to safety performance, and quantification methods for measurement. The purpose is to develop a method to relate these items to a probabilistic assessment of human error. Organizational model of nuclear power plant includes operating core, middle line, strategic apex, technostructure, and support staff. Organizational characteristics include coordinating mechanisms (standardization), design parameters (formalization, functional grouping, vertical centralization), and contingency factors (age, size, regulation). Supervisory/management functions and processes include design of standards, application, feedback, and override. These are the key processes of the standardization of work. Quantification methods include identification of key personnel, resource allocation, assessment of organizational congruence by means of standardized inventory given to all levels in organization, observation of supervisors and managers to develop a standardized taxonomy of behaviors, etc. Outcomes should be ability to differentiate plants and determine quality/effectiveness

of management teams. Overheads call for sample applications of methodology.

Chockie et. al. "The Right Data for the Right Decision: Performance Indicators for Different Management and Regulatory Needs," Battelle HARC, 9/10/88.

Provides a discussion of the different needs of users for past performance data. The paper distinguishes between 5 user categories - NRC, PUC, utility, plant, and department management. It examines 5 performance indicator attributes - human/hardware system, cause vs. consequence, safety vs. economic performance, absolute vs. trended performance, and level of detail.

Haber, et. al., "An Organizational Model of a Nuclear Power Plant," Brookhaven, April 27, 1988.

Very similar to the Brookhaven National Laboratory work discussed above. Depends heavily on Mintzberg's The Structuring of Organizations for five basic parts of an organization - strategic apex, etc. (see above) and five basic organization structures - simple, machine, professional, divisionalized, and adhocracy. "The NPP is probably best described as a machine bureaucracy with some differences in structure within the operating core." Appendix A is very helpful in that it describes the basic organizational units of a nuclear power plant - operations, maintenance, instrumentation and control, quality assurance, testing and performance, health physics, chemistry, independent safety engineering, licensing, outage management, etc. Conference paper "Model Development for the Determination of the Influence of Management on Plant Risk" (undated) basically repeats same information.

Hendrickson et. al., Financial Qualifications Review of Applicants for Nuclear Power Plant Construction Permits, NUREG/CR-5218, September 1988.

This is an evaluation of the need for NRC to do financial qualifications reviews prior to licensing (construction permit application). NRC attempted to discontinue this practice but was overruled by the courts. Apparently, two prior analyses - one by National Economic Research Associates, Palm Beach, Florida, and one by Cygna Energy Services, Boston, Mass., - found no relation between financial condition at time of construction permit application and subsequent safety performance. This study examines the relationship between the following financial indicators -- bond rating, interest coverage ratio, debt/asset ratio, debt/equity ratio, and rate of return on equity -- and SALP ratings. The SALP ratings are the long term averages of the SALP scores in the four key functional areas. A scatterplot matrix analysis is carried out as well as a "more formal test" via correlational analysis. No relationships between the financial indicators and subsequent safety performance are found. Forty three utilities are included

in this analysis. The study concludes that the failure to detect a relationship "does not prove conclusively that no relationship exists." Both safety and financial performance are highly variable and the variation may be due to factors like management, training, age of the plants, human performance, etc. "With all the factors that can influence safety..., the effect of financial qualifications at one point in time, long before the plant begins to operate, is likely to be relatively minor."

INDEPENDENT VARIABLES

<u>Measured</u>

bond rating
interest coverage ratio
debt/asset ratio
debt/equity ratio
rate of return on equity

DEPENDENT VARIABLES

<u>Measured</u>

SALP ratings - long term averages in four functional areas

RESULTS

A "scatterplot matrix analysis" is carried out as well as a "more formal test" via correlational analysis. No relationships between the financial indicators <u>at time of application for permit to begin construction</u> and subsequent safety performance are found.

Forty three or all nuclear utilities are included in this analysis.

Human Synergistics, <u>Organizational Culture Inventory</u>, 1987.

An instrument that measures 12 cultural "types" including a humanistic-helpful culture, an affiliative culture...a dependent culture, an avoidance culture, an oppositional culture, a power culture....a self-actualizing culture, etc. The humanistic-helpful culture or some variant on it is preferred to avoidance, power cultures etc.

Interoffice Task Group on Performance Indicators, <u>Performance Indicator Program Plan for Nuclear Power Plants</u>, September 1986.

This is the background report for the Stello memo. Seventeen performance indicators at 50 plants at 30 sites were initially selected for a trial program. The main approach to validation was to see if the indicators were related to SALP scores. Several of the indicators correlated with the SALP scores and several did not. Eight indicators were recommended for the final program based on

a plant safety logic model, capacity to predict previous problems, and comparability with the INPO approach. The final indicators were (1) automatic scrams, (2) safety system actuations, (3) significant events, (4) safety system failures, (5) forced outage rate, (6) maintenance backlog, (7) enforcement action index, and (8) mean time between forced outages induced by equipment failures. A recommendation is made to collect these data on a quarterly basis in order to make decisions about poor or declining performance.

INDEPENDENT VARIABLES

Measured

age
size
reactor type
scrams of various kinds
safety system actuations
significant events
forced outages
unplanned shutdowns
audit items
average age of audit items
ratio of open to closed work requests
enforcement actions
vacancies
experience of operators
no. of licenses on site
maintenance indicator

DEPENDENT VARIABLES

Measured

scrams
safety system actuations
safety system failures
forced outage rates
no. of unplanned shutdowns
enforcement action index
SALP scores

RESULTS

Everything appears to significantly correlate with SALP scores except for vacancies and experience.

Analysis was done at 50 plants at 30 sites. Data from 1984-85-86 are used in this analysis. Some effort is made to take into account

structural variables such as age, region, etc., but only simple correlational analysis is used.

Komaki et. al., "Development of an Operant-Based Taxonomy and Observational Index of Supervisory Behavior," Journal of Applied Psychology, Vol. 71, no. 2, 1986.

Uses theory of operant conditioning (major impact on behavior produced by antecedents, monitors, and consequences) to develop supervisory taxonomy and index. Claims that this approach is superior to prior management study (e.g. Mintzberg) because it is firmly rooted in psychological theory as well as being based on observing managers in action. Although some empirical work is reported (a test of the reliability of the measure), this work is not directly related to nuclear power safety or performance outcomes. Authors admit that framework has to be tested to see if there is any correlation with supervisory effectiveness.

Marcus, "Implementing Externally Induced Innovations: A Comparison of Rule-bound and Autonomous Approaches," Academy of Management Journal, June 1988.

This paper tries to determine the effect of different implementation styles (rule-bound and autonomous) on safety performance outcomes (human error LERs). Data from 1981 and 1982 on a small sample of 13 nuclear power plants where the author conducted in-depth interviews of safety review personnel were used. Variables in the analysis include total LERs, significant events, SALP ratings, and capacity factors. The control variables are age, profitability, size, and long-term debt. The analysis strategy is to see if past performance determines an implementation approach and if in turn the implementation approach then determines subsequent performance. The author is searching for the existence of what he calls vicious and beneficent cycles. A vicious cycle means that poor performance constrains the choices that nuclear power managers have and that with less choice performance further deteriorates. On the other hand, good performance opens room for managerial discretion which can result in further improvements in performance. Simple correlation analysis shows significant relations between an autonomous implementation approach and low occurrence of events, with a very significant correlation between the autonomous approach and low incidence of human error events. There are also significant correlations between autonomy and high profitability, between low profitability and the number of events, and between low profitability and a high number of human error events. A profit analysis is done which shows that prior performance indeed affects the implementation approaches. A regression analysis then shows that implementation approaches controlling for age, profitability, etc. affect subsequent performance. An implication is that performance gaps between strong and weak plants may increase when NRC introduces new requirements.

INDEPENDENT VARIABLES

Measured

past performance
implementation approaches (autonomous and rule-bound as determined by document analysis and site interviews)
age
profitability
debt
size

DEPENDENT VARIABLES

Measured

LERs
human error LERs
significant events
capacity factors
SALP scores

RESULTS

Simple correlation analysis shows significant relations between an autonomous implementation approach and low occurrence of events, with a very significant correlation between the autonomous approach and low incidence of human error events.

There are also significant correlations between autonomy and high profitability, between low profitability and the number of events, and between low profitability and a high number of human error events.

A profit analysis is done which shows that prior performance indeed affects the implementation approaches.

A regression analysis then shows that implementation approaches controlling for age, profitability, etc. affect subsequent performance.

Data from 1981 and 1982 on a small sample of 13 nuclear power plants where the author conducted in-depth interviews of safety review personnel were used.

Olson et. al. Development of Programmatic Performance Indicators, September 1988 draft NUREG/CR-5241.

This report is interesting for many reasons. First, it develops and tests a management indicator that previously has not been analyzed - how quickly and completely plant and utility management move to resolve safety issues that have been raised by NRC. Using

1986 data from a sample of 24 plants, three backlog measures were constructed. A second analysis was performed using revised data from 72 plants. The report finds that the number of issues in backlog and the number of days in backlog are correlated with Systematic Assessment of Licensee Programs (SALP) ratings and several of the direct performance indicators (PIs). Second, the report finds no correlation between operator exam scores and safety performance. Third, the report finds correlations between Licensee Event Report (LER) cause codes (e.g. operator errors, other personnel errors, procedural errors, administrative control problems, etc.) and safety as measured by SALP and the direct PIs. 1985 and 1986 data are used.

INDEPENDENT VARIABLES

Measured

three backlog measures (how quickly and completely plant and utility management move to resolve safety issues)
operator exam scores and pass rates
operator error
personnel error
maintenance problems
design/installation problems
procedure errors
administrative control problems
equipment failures
unknown causes

DEPENDENT VARIABLES

Measured

SALP
scrams
safety system actuations
significant events
safety system failures
forced outage rate
equipment forced outage

RESULTS

Significant correlations found between backlog measures and forced outage rates and equipment outage rates. No other significant correlations. The significant correlations hold up pretty well using different combinations of years 1980-1986 and technology configurations. They hold up for the smaller sample of 26 plants and the larger sample of 72.

There are no significant correlations between pass rates or exam scores with operator error or personnel error. The operator exam

scores correlate significantly, however, with some of the final performance indicators such as scrams and safety system actuations (see p. 3-10) but the pattern is not consistent. These data come from 75 plants from 1985-86.

There are significant correlations between most of the LER cause codes and SALP scores. Personnel error, maintenance problems, design/installation problems, procedure errors, equipment failures significantly relate to the SALP scores, but operator error and administrative control problems do not. There are few significant correlations between cause codes in 1985 and direct performance indicators in 1986. However, there are many such correlations between cause codes in 1986 and direct performance indicators in 1986. Particularly well predicted are safety system actuations and forced outage rates (see p. 4-22). These data come from all plants in 1985 and 1986.

Olson et. al. An Initial Empirical Analysis of Nuclear Power Plant Organization and Its Effect on Safety Performance, November 1984 NUREG/CR-3737.

In this report a number of variables are created based on organizational structure:

> vertical structure - number of ranks and ratio of supervisors to subordinates
>
> horizontal structure - division of the organization into work and administrative units
>
> coordinative structure - the way that work units are linked.

It also combines LERs, forced outages, violations, and SALP data and adjusts them for vendor, age, size, and region effects using factor analysis to create four general indicators of plant safety performance: Regulatory Noncompliance, Human Error, Hardware Failure, and Plant Nonreliability. It then correlates the measures of organizational structure with the plant safety performance indicators.

INDEPENDENT VARIABLES

Measured

vertical structure - no. of ranks and ratio of supervisors to subordinates

horizontal structure - division of the organization into work and administrative units

coordinative structure - the way that work units are linked

DEPENDENT VARIABLES

<u>Measured</u>

regulatory noncompliance
human error
hardware failure
plant nonreliability.

(combines LERs, forced outages, violations, and SALP data and adjusts them for vendor, age, size, and region effects using factor analysis to create four general indicators of plant safety performance)

RESULTS

The findings are that

plants with a larger number of vertical ranks generally had poorer safety performance

plants with more departments and a larger ratio of subordinates to supervisors (except in operations) generally had better safety records

plants with better developed coordinative mechanisms tend to have better safety records.

The analysis is limited to about two thirds of the operating plants in 1981.

Olson et. al. <u>Objective Indicators of Organizational Performance of Nuclear Power Plants</u>, January 1986, NUREG/CR-4378.

Another very interesting work. The idea here was to determine if past performance measures (human error and system effects LERs, scrams, forced outages, and major violations) were related to penultimate safety measures (significant events and radiological exposures and releases). The performance measures were predictive of the significant events and to some extent of the radiological releases, but not of radiological exposure. Regression analysis indicated that the addition of controls for plant characteristics did not substantially affect the results. The analysis uses 1981-83 data.

INDEPENDENT VARIABLES

Measured

Percent of year refueling
Reactor type (BWR or PWR)
Size (Net MWe)
Region
Age (months in operation)
human error and system effects LERs
scrams
forced outages
major violations
% of year refueling
plant type
size
region
age

DEPENDENT VARIABLES

Measured

significant events
radiological exposures
radiological releases

RESULTS

Significant variation is found with respect to reactor type, region, age, % of year in refueling and abnormal releases. No significant variation with respect to significant events. The performance measures (human error and system effect LERs, scrams, forced outages, and major violations) were predictive of the significant events and scrams, forced outages, and human error LERs were predictive of the radiological releases, but nothing consistently predicted radiological exposure. Regression analysis indicated that the addition of controls for plant characteristics did not substantially affect the results.

The analysis uses 1981-83 data for all plants.

Osborn and Jackson, "Leaders, Riverboat Gamblers, or Purposeful Unintended Consequences in the Management of Complex, Dangerous Technologies," Academy of Management Journal, Vol. 31, No. 4, December 1988, 924-947.

This paper starts with an absorbing discussion of such structural issues as plant size and age, safety of different designs (BWRs/PWRs), region, construction practices and such management issues as administrative capabilities for handling tight coupling and the "competence destroying change" of movement from older steam

technologies to nuclear. It focuses, however, on two key variable categories: (1) commitment to nuclear power, i.e. companies with more nuclear plants and greater financial investment in the technology should have greater managerial and administrative competence and should have a greater incentive to invest in safety; and (2) prior earnings and safety, i.e. ability to afford non-capital expenditures - operating crews, engineering support, etc. - of post TMI requirements. It introduces a fascinating theoretical rationale (the literature on gamblers, speculators, and entrepreneurs) for examining non-linear relations and hypothesizes that there will be a curvilinear relation between commitment and prior earnings growth and violations. Data from 42 utilities in the 1975-81 period is used in the analysis. The dependent variables are: plant reliability - the ratio of total operating hours to total hours the plants could have operated had it not experienced a forced shut down; and violations with the focus being on major violations. The results show a substantial correlation between number of reactors and major violations. Higher reliability is associated with more favorable prior earnings and greater commitment. A very interesting discussion of the graphical display of the findings follows, where the ideas of leaders, riverboat gamblers, and purposeful unintended consequences are discussed.

INDEPENDENT VARIABLES

<u>Measured</u>

plant size
age
different designs (BWRs/PWRs)
region
construction company
architect engineer
no. of nuclear plants
financial investment in the technology
earnings

DEPENDENT VARIABLES

<u>Measured</u>

violations - various severity categories
plant reliability - the ratio of total operating hours to total hours the plants could have operated had it not experienced a forced shut down

RESULTS

A substantial correlation between number of reactors and major violations and between number of reactors and plant reliability.

Higher reliability is associated with more favorable prior earnings.
Data from 42 utilities in the 1975-81 period is used in the analysis.

Osborn, et. al. Organizational Analysis and Safety for Utilities with Nuclear Power Plants, NUREG/CR-3215, 2 volumes, August 1983.

These two volumes are the most comprehensive and thorough examination of the organization and management literature as it relates to nuclear power that is available. In volume I there are discussions of: lessons from other industries; the utility environment including ownership and control, regulation, self-regulation, and the role of the vendors; the context including size, organizational governance, and conflicting technical demands; organizational design including issues relating to mechanistic and organic pattern and diversity; intermediate outcomes including quality, efficiency, innovation, compliance, and employee turnover; final safety indicators; and the use of organizational analysis to help solve identified problems. Twenty six propositions are developed which cover environment, size, technology, organizational governance, organizational design, and congruity. These propositions are derived in an excellent fashion and are based on a wide reading and knowledge of the relevant literature. In volume II there are separate chapters on

1. Organization Design and Safety
2. Organizational Governance
3. Utility Environment and Safety Related Outcomes
4. Assessments by Selected Federal Agencies
5. A Review of Data Sources in the Nuclear Power Industry
6. Existing Safety Indicators: A Critical Analysis

Reason, "Resident Pathogens and Risk Management," draft of paper presented for World Bank Workshop on Safety Control and Risk Management, Oct. 18-20, 1988.

This is a very interesting paper which defines such terms as errors, slips, and mistakes in a much more rigorous manner than is usually done. For example, "if the error occurs during the planning process, it is a mistake; if it happens during the course of executing the plan, it is a slip." Violations - deviations from practices deemed necessary by designers, managers, and regulators - also have to be distinguished from errors that occur because of cognitive limitations. Routine violations need to be distinguished from exceptional violations. Probably the most important distinction is between active failures and latent failures. Active failures "make their effects felt almost immediately. They are usually associated with the activities of the 'frontline operators...Latent failures, on the other hand, are those whose adverse consequences may lie dormant within the system for a long

time, only becoming evident when they combine with other factor to breach the system's defenses." Reason does case study analyse of TMI, Bhopal, Challenger, Chernobyl, etc. to show that th pathway for propagating errors and violations always starts wit latent failures. The second figure in this document is ver relevant in that he suggests that latent failures originate i resource scarcity - insufficient money, capital, personne expertise, and time. This paper provides a very tightly organized argument for why we should be interested in plant resources as it develops accident pathways and shows their origins in insufficient resources.

Ryan, "Human Performance Measurement:Issues and Challenges," Office of Nuclear Regulatory Research, 9/10/88.

A very stimulating paper that is a fundamental critique of past efforts and poses a fundamental challenge to future research. Ryan cites evidence that 30 to 80 percent of all NPP accidents are initiated, exacerbated, or recovered through actions of individuals, teams, and organizations. "This gives rise to a need for measuring human performance on a near realtime basis, for interpreting the safety significance of those measures, and for modifying individual, team and human organization behavior.." He discusses the need for logic models which prescribe explicit rules by which behavior elements are combined as opposed to mere individual indicators and measures of performance. Some of the behavior elements he mentions are fatigue, stress, attitudes. Superimposed on these are more stable task oriented elements such as staffing, training, and operating procedures. Finally, superimposed on task oriented mechanisms are supervision and management and organizational climate. Ryan stresses the importance of understanding the "synergism" among behavioral elements. With regard to so-called dependent variables Ryan distinguishes between "ultimate, penultimate, intermediate, or immediate" depending on their spatial and temporal relation to antecedent performance measures. He maintains that it is especially troubling that we lack objective safety criteria and objective performance and sampling techniques. Hypothetical constructs (SALP) and intermediate safety criteria (e.g. plant outages, safety system actuations) are not used appropriately. For the most part, data are not normally distributed. Nevertheless, parametric statistics are used to analyze them. Ryan therefore argues that "it is highly unlikely that performance data, no matter how well the collection process is controlled, will lend themselves to analysis using standard linear and multiple regression techniques." This is a fundamental challenge to any effort to undertake empirical work.

Ryan, "Organization and Management Research" memo from Ryan to Coffman, Chief of Reliability and Human Factors Branch, July 13, 1988.

Ryan sets out a rationale for research in the area. NRC investigations of major incidents show personnel, supervisory, managerial problems at the core of these incidents. "A complete understanding of an abnormal event requires that we take into account organizational and management factors which are present prior to the event and which act as catalysts for personnel exchanges and overt actions during the event." He envisions a four stage research strategy which will first involve developing a dynamic model of the human organization, second will involve specifying key factors that can influence organizational behavior including key supervisor and manager functions and roles, third will involve information collection, and fourth will involve indices for quantification including "raw or normalized scores, error probability curves, or regression lines."

Stello, Performance Indicators, October 28, 1986.

This document establishes 8 performance indicators for NRC monitoring and evaluation. (Later, they were reduced to 6.) The policy document by Stello distinguishes direct and indirect indicators. Key assumptions are that SALP is the cornerstone of the NRC effort and that detecting and correcting poor and declining performance is necessary. Indicators were selected based on some of the following attributes: availability, non-susceptibility to manipulation, comparability between licensees, independence from each other, and predictive of future performance. The strongest contributor to the correlation with the SALP ratings was the Enforcement Action Index.

Taylor, "Kewaunee's Plant Management Practices Set An Example," Nuclear News, May 1985.

Discusses plant management practices at an exemplary facility in Wisconsin. Key factors appear to be worker attitudes, personnel training, and learning lessons from and during outages.

Thurber, "A Description of Maintenance Initiatives Practices and Regulations..., August 12, 1988, PNL

Overheads from a presentation to support NRC's development of a proposed rule. Interesting comparative information on Japan (long term view and trust), France (emphasis on availability and learning from operating experience), Germany (planning, coordination, and craftsmanship), FAA (qualitative safety goals), U.S. military (unlimited resources, extensive centralized data collection).

Weick, "Organizational Culture and High Reliability," California Management Review, Winter 1987.

Mostly relates to training. The point seems to be that people who manage complex systems are not sufficiently complex to sense and anticipate problems. Trial and error learning with NPPs is

unacceptable. Substitutes for this type of learning come "in the form of imagination, vicarious experiences, stories, simulation, and other symbolic representations (p. 112)." "The basic idea is that a system that values stories, storytellers, and storytelling will be more reliable than a system that derogates these substitutes for trial and error (p. 113)."

Wreathall, et. al. (SAIC), Framework of Analysis for the Identification and Selection of Programmatic Performance Indicators, May 1988.

A brief document, useful in its detailed flow charts which break down relations between corporate management, site management, training, engineering support, purchasing/construction, maintenance, operations, other plant functions; performance analysis, quality assurance, physical plant systems, and output (availability, scrams, etc. Flow charts are discussed in text.

APPENDIX D

CORRELATIONS AMONG VARIABLES USED[1]

	1	2	3	4	5	6	7	8	9	10	11	12	13
1 SCRAMS	1.00												
	0.00												
2 SSACTUAM	0.55	1.00											
	0.00	0.00											
3 SIGEVENT	0.68	0.38	1.00										
	0.00	0.00	0.00										
4 SSFAILM	-0.17	0.06	0.27	1.00									
	0.23	0.62	0.02	0.00									
5 CRITHRM	0.26	-0.13	-0.07	-0.29	1.00								
	0.07	0.29	0.57	0.01	0.00								
6 FOROUTAGE	0.32	0.26	0.38	0.11	-0.10	1.00							
	0.02	0.03	0.00	0.38	0.39	0.00							
7 OUTRATEM	-0.18	0.20	0.03	0.16	-0.88	0.14	1.00						
	0.20	0.09	0.78	0.18	0.00	0.24	0.00						
8 SALPTOTS	-0.17	0.12	0.34	0.37	-0.69	0.00	0.55	1.00					
	0.33	0.38	0.01	0.01	0.00	0.98	0.00	0.00					
9 PLANTSIZ	0.36	0.28	0.20	0.02	-0.37	0.13	0.35	0.41	1.00				
	0.01	0.02	0.09	0.84	0.00	0.29	0.00	0.00	0.00				
10 BABWIL	-0.10	0.04	0.10	-0.10	-0.18	0.40	0.25	-0.07	0.03	1.00			
	0.46	0.73	0.39	0.42	0.13	0.00	0.03	0.64	0.82	0.00			
11 COMBENG	0.22	0.10	0.04	-0.10	0.10	0.02	-0.03	-0.23	0.08	-0.12	1.00		
	0.12	0.40	0.73	0.39	0.43	0.85	0.82	0.10	0.48	0.32	0.00		
12 WESTINGH	0.17	0.02	0.07	-0.26	0.24	-0.09	-0.12	0.03	0.09	-0.26	-0.35	1.00	
	0.24	0.87	0.58	0.03	0.04	0.46	0.33	0.81	0.46	0.03	0.00	0.00	
13 NORTHEAS	0.06	-0.12	0.05	0.03	0.15	0.07	-0.13	-0.50	-0.07	0.06	0.14	-0.18	1.00
	0.67	0.32	0.69	0.81	0.22	0.53	0.27	0.00	0.54	0.60	0.22	0.13	0.00

[1] Significance level of correlation appears under correlation coefficient. A value of .00 implies a significance beyond .005.

	1	2	3	4	5	6	7	8	9	10	11	12	13
14 SOUTH	-0.08	0.17	0.06	0.02	-0.20	0.05	0.24	0.18	0.25	-0.02	-0.14	0.19	-0.4[illegible]
	0.59	0.17	0.60	0.89	0.09	0.66	0.04	0.19	0.03	0.87	0.25	0.11	0.0[illegible]
15 MIDWEST	-0.30	-0.23	-0.32	0.09	0.02	-0.18	-0.10	0.14	-0.26	-0.07	-0.15	-0.04	-0.3[illegible]
	0.03	0.05	0.01	0.46	0.85	0.13	0.39	0.32	0.03	0.56	0.20	0.74	0.0[illegible]
16 WEST	0.71	0.24	0.22	-0.11	0.03	0.02	-0.03	-0.03	0.02	-0.09	0.17	0.04	-0.17
	0.00	0.04	0.07	0.36	0.83	0.85	0.81	0.85	0.87	0.45	0.14	0.73	0.15
17 AGE	-0.45	-0.30	-0.15	0.09	0.10	-0.14	-0.16	-0.22	-0.82	-0.01	-0.14	-0.09	0.15
	0.00	0.01	0.22	0.44	0.41	0.25	0.17	0.11	0.00	0.96	0.23	0.45	0.20
18 NOPLANTS	-0.04	-0.13	-0.10	0.17	-0.19	-0.02	0.02	0.22	0.18	-0.02	-0.15	-0.12	-0.40
	0.76	0.29	0.41	0.16	0.12	0.85	0.88	0.12	0.13	0.85	0.19	0.33	0.00
19 NOMAJV81	-0.26	-0.15	-0.02	0.09	-0.38	-0.09	0.29	0.41	0.18	-0.11	-0.09	0.05	-0.01
	0.07	0.21	0.86	0.44	0.00	0.46	0.01	0.00	0.11	0.36	0.44	0.68	0.90
20 NOMAJV82	-0.22	0.02	-0.04	0.15	-0.29	-0.13	0.09	0.22	0.01	-0.09	-0.19	-0.11	-0.12
	0.11	0.84	0.76	0.21	0.01	0.28	0.46	0.11	0.94	0.46	0.11	0.36	0.31
21 NOMAJV83	-0.12	-0.01	0.05	0.16	-0.23	-0.12	0.07	0.33	0.15	0.00	-0.06	-0.23	-0.03
	0.42	0.95	0.67	0.20	0.06	0.34	0.58	0.02	0.21	0.97	0.63	0.05	0.83
22 NOMAJV84	-0.38	-0.10	0.03	0.35	-0.63	-0.14	0.59	0.51	0.11	-0.01	-0.17	-0.11	-0.09
	0.01	0.42	0.79	0.00	0.00	0.26	0.00	0.00	0.36	0.91	0.15	0.35	0.46
23 NOMAJV85	-0.18	-0.06	-0.08	0.14	-0.48	-0.17	0.38	0.53	0.28	-0.11	-0.16	0.05	-0.11
	0.21	0.64	0.53	0.24	0.00	0.16	0.00	0.00	0.02	0.34	0.18	0.65	0.37
24 LER81	-0.20	0.17	-0.14	0.18	-0.20	0.12	0.23	0.19	0.11	-0.05	-0.09	0.06	-0.02
	0.15	0.15	0.23	0.13	0.09	0.31	0.06	0.18	0.34	0.69	0.46	0.63	0.87
25 LER82	-0.24	0.05	-0.20	0.11	-0.15	0.06	0.08	0.20	0.19	-0.08	0.06	-0.05	-0.04
	0.11	0.72	0.12	0.40	0.25	0.64	0.53	0.14	0.10	0.50	0.64	0.65	0.72
26 LER83	-0.17	0.00	-0.16	0.04	-0.13	-0.02	0.13	0.19	0.30	-0.06	0.06	0.00	-0.06
	0.24	0.98	0.18	0.77	0.29	0.88	0.28	0.17	0.01	0.64	0.61	0.98	0.61

	1	2	3	4	5	6	7	8	9	10	11	12	13
27 LER84	-0.06	0.01	-0.06	0.20	-0.19	-0.05	0.06	0.40	0.35	-0.17	-0.07	-0.05	-0.10
	0.66	0.96	0.64	0.09	0.12	0.70	0.60	0.00	0.00	0.15	0.56	0.67	0.38
28 LER85	0.24	0.32	0.11	0.14	-0.20	0.14	0.09	0.42	0.51	-0.22	-0.00	-0.05	-0.13
	0.08	0.01	0.35	0.24	0.10	0.24	0.44	0.00	0.00	0.06	0.99	0.67	0.27
29 DE81	0.16	0.04	0.19	-0.02	0.02	0.19	0.02	-0.00	0.04	0.10	-0.12	-0.08	0.19
	0.27	0.76	0.11	0.87	0.88	0.11	0.87	0.98	0.74	0.39	0.30	0.49	0.10
30 DE82	0.01	0.03	0.01	-0.05	0.00	0.11	0.01	-0.09	-0.05	0.08	-0.09	-0.20	0.17
	0.95	0.82	0.96	0.66	0.997	0.37	0.91	0.55	0.69	0.51	0.45	0.09	0.15
31 DE83	0.08	0.07	0.14	0.04	-0.08	0.11	0.09	0.10	0.08	0.12	-0.00	-0.12	0.21
	0.56	0.53	0.25	0.77	0.50	0.35	0.44	0.48	0.49	0.30	0.98	0.30	0.08
32 DE84	0.03	0.12	0.11	0.15	-0.10	0.18	0.10	0.11	0.08	0.09	-0.07	-0.12	0.12
	0.86	0.32	0.35	0.20	0.43	0.14	0.39	0.42	0.49	0.43	0.56	0.29	0.31
33 DE85	0.06	-0.01	-0.02	-0.06	-0.03	0.11	0.08	-0.09	0.01	0.07	-0.12	0.04	-0.01
	0.70	0.91	0.89	0.65	0.77	0.36	0.49	0.53	0.93	0.58	0.30	0.71	0.96
34 ROA81	-0.07	-0.16	-0.23	-0.10	0.03	-0.19	-0.07	-0.14	-0.03	0.05	0.05	0.05	-0.02
	0.61	0.19	0.06	0.42	0.81	0.11	0.58	0.33	0.81	0.67	0.69	0.70	0.88
35 ROA82	-0.08	-0.18	-0.33	-0.10	0.11	-0.28	-0.09	-0.20	0.01	0.06	0.18	-0.08	0.05
	0.58	0.14	0.00	0.43	0.36	0.02	0.45	0.15	0.91	0.60	0.13	0.48	0.67
36 ROA83	-0.18	-0.23	-0.46	-0.26	0.14	-0.23	-0.11	-0.22	-0.10	0.10	0.13	-0.10	0.03
	0.20	0.05	0.00	0.03	0.24	0.05	0.34	0.11	0.40	0.42	0.26	0.39	0.79
37 ROA84	-0.19	-0.21	-0.28	-0.10	0.12	-0.19	-0.11	-0.11	0.02	0.10	0.23	-0.08	0.19
	0.19	0.07	0.02	0.40	0.33	0.11	0.36	0.45	0.88	0.41	0.05	0.47	0.11
38 ROA85	-0.21	-0.18	-0.24	-0.08	0.12	-0.24	-0.07	-0.14	0.05	0.04	0.21	-0.06	0.16
	0.14	0.13	0.05	0.51	0.32	0.04	0.55	0.31	0.65	0.71	0.07	0.59	0.17

	14	15	16	17	18	19	20	21	22	23	24	25	26
1 SCRAMM	-0.08	-0.30	0.71	-0.45	-0.04	-0.26	-0.22	-0.12	-0.38	-0.18	-0.20	-0.23	-0.17
	0.59	0.03	0.00	0.00	0.76	0.07	0.11	0.42	0.01	0.21	0.15	0.11	0.24
2 SSACTUAM	0.17	-0.23	0.24	-0.30	-0.13	-0.15	0.02	-0.01	-0.10	-0.06	0.17	0.04	0.00
	0.17	0.05	0.04	0.01	0.29	0.21	0.84	0.95	0.42	0.64	0.15	0.72	0.98
3 SIGEVENT	0.06	-0.32	0.22	-0.15	-0.10	-0.02	-0.04	0.05	0.03	-0.08	-0.14	-0.19	-0.16
	0.60	0.01	0.07	0.22	0.41	0.86	0.76	0.67	0.79	0.53	0.23	0.12	0.18
4 SSFAILM	0.02	0.09	-0.11	0.09	0.17	0.09	0.15	0.16	0.35	0.14	0.18	0.10	0.04
	0.89	0.46	0.36	0.44	0.16	0.44	0.21	0.20	0.00	0.24	0.13	0.40	0.77
5 CRITHRM	-0.20	0.02	0.03	0.10	-0.19	-0.38	-0.29	-0.23	-0.63	-0.48	-0.20	-0.14	-0.13
	0.09	0.85	0.83	0.41	0.12	0.00	0.01	0.06	0.00	0.00	0.09	0.25	0.29
6 FOROUTAGE	0.05	-0.18	0.02	-0.14	-0.02	-0.09	-0.13	-0.12	-0.14	-0.17	0.12	0.06	-0.02
	0.66	0.13	0.85	0.25	0.85	0.46	0.28	0.34	0.26	0.16	0.31	0.64	0.88
7 OUTRATEM	0.24	-0.10	-0.03	-0.16	0.02	0.29	0.09	0.07	0.59	0.38	0.23	0.08	0.13
	0.04	0.39	0.81	0.17	0.88	0.01	0.46	0.58	0.00	0.00	0.06	0.53	0.28
8 SALPTOT5	0.18	0.14	-0.03	-0.22	0.22	0.41	0.22	0.33	0.51	0.53	0.19	0.20	0.19
	0.19	0.32	0.85	0.11	0.12	0.00	0.11	0.02	0.00	0.00	0.18	0.14	0.17
9 PLANTSIZ	0.25	-0.26	0.02	-0.82	0.18	0.18	0.01	0.15	0.11	0.28	0.11	0.19	0.30
	0.03	0.03	0.87	0.00	0.13	0.11	0.94	0.21	0.36	0.02	0.34	0.10	0.01
10 BABWIL	-0.02	-0.07	-0.09	-0.01	-0.02	-0.11	-0.09	0.00	-0.01	-0.11	-0.05	-0.08	-0.06
	0.87	0.56	0.45	0.96	0.85	0.36	0.46	0.97	0.91	0.34	0.69	0.50	0.64
11 COMBENG	-0.14	-0.15	0.17	-0.14	-0.15	-0.09	-0.19	-0.06	-0.17	-0.16	-0.09	0.06	0.06
	0.25	0.20	0.14	0.23	0.19	0.44	0.11	0.63	0.15	0.18	0.46	0.64	0.61
12 WESTINGH	0.19	-0.04	0.04	-0.09	-0.12	0.05	-0.11	-0.23	-0.11	0.05	0.06	-0.05	0.00
	0.11	0.74	0.73	0.45	0.33	0.68	0.36	0.05	0.35	0.65	0.63	0.65	0.98
13 NORTHEAS	-0.43	-0.35	-0.17	0.15	-0.40	-0.01	-0.12	-0.03	-0.09	-0.11	-0.02	-0.04	-0.06
	0.00	0.00	0.15	0.20	0.00	0.90	0.31	0.83	0.46	0.37	0.87	0.72	0.61

26		14	15	16	17	18	19	20	21	22	23	24	25	26
-0.17	14 SOUTH	1.00												
0.24		0.00												
0.00	15 MIDWEST	-0.46	1.00											
0.98		0.00	0.00											
-0.16	16 WEST	-0.23	-0.18	1.00										
0.18		0.05	0.12	0.00										
0.04	17 AGE	-0.27	0.25	-0.07	1.00									
0.77		0.02	0.03	0.58	0.00									
-0.13	18 NOPLANTS	0.16	0.35	-0.17	-0.02	1.00								
0.29		0.18	0.00	0.15	0.89	0.00								
-0.02	19 NOMAJV81	0.05	-0.02	0.04	0.12	-0.16	1.00							
0.88		0.69	0.85	0.72	0.30	0.18	0.00							
0.13	20 NOMAJV82	0.17	-0.08	0.10	0.14	0.04	0.31	1.00						
0.28		0.14	0.49	0.41	0.25	0.73	0.01	0.00						
0.19	21 NOMAJV83	0.08	0.00	-0.10	0.03	0.26	0.14	0.36	1.00					
0.17		0.50	0.996	0.39	0.81	0.03	0.24	0.00	0.00					
0.30	22 NOMAJV84	0.22	0.01	-0.17	0.15	0.04	0.48	0.24	0.21	1.00				
0.01		0.06	0.91	0.14	0.21	0.71	0.00	0.04	0.08	0.00				
-0.06	23 NOMAJV85	0.11	0.07	-0.06	-0.28	0.29	0.16	-0.03	-0.06	0.18	1.00			
0.64		0.38	0.57	0.59	0.02	0.01	0.17	0.80	0.64	0.14	0.00			
0.06	24 LER81	0.36	-0.16	-0.25	0.03	-0.05	0.20	0.28	0.20	0.29	-0.07	1.00		
0.61		0.00	0.17	0.03	0.78	0.69	0.08	0.02	0.10	0.01	0.58	0.00		
0.00	25 LER82	0.20	-0.06	-0.09	-0.16	-0.07	0.17	0.27	0.25	0.09	0.13	0.63	1.00	
0.98		0.09	0.58	0.43	0.19	0.57	0.14	0.02	0.03	0.45	0.27	0.00	0.00	
0.06	26 LER83	0.26	-0.06	-0.17	-0.31	-0.02	0.18	-0.01	0.08	0.10	0.18	0.44	0.75	1.00
0.61		0.03	0.63	0.15	0.01	0.88	0.12	0.91	0.49	0.40	0.12	0.00	0.00	0.00

	14	15	16	17	18	19	20	21	22	23	24	25	26
27 LER84	0.07	0.14	-0.08	-0.39	0.22	-0.06	-0.04	0.12	-0.02	0.55	0.00	0.39	0.44
	0.55	0.25	0.50	0.00	0.06	0.64	0.71	0.32	0.85	0.00	0.98	0.00	0.00
28 LER85	0.01	0.02	0.09	-0.52	0.07	0.04	0.08	0.07	-0.00	0.22	-0.04	0.17	0.15
	0.96	0.86	0.43	0.00	0.56	0.72	0.50	0.55	0.98	0.07	0.74	0.15	0.20
29 DE81	-0.10	-0.09	-0.00	-0.09	0.07	-0.11	-0.19	-0.09	-0.23	-0.00	-0.26	-0.14	-0.08
	0.39	0.44	0.98	0.47	0.53	0.38	0.10	0.47	0.06	0.98	0.03	0.24	0.51
30 DE82	-0.17	-0.05	0.09	-0.05	0.02	-0.08	-0.15	-0.14	-0.17	-0.03	-0.29	-0.19	-0.22
	0.14	0.70	0.46	0.70	0.84	0.49	0.20	0.24	0.15	0.81	0.01	0.12	0.07
31 DE83	-0.09	-0.14	0.04	-0.12	0.02	-0.01	-0.13	-0.08	-0.15	0.03	-0.24	-0.12	-0.14
	0.44	0.24	0.72	0.31	0.87	0.93	0.28	0.51	0.22	0.79	0.04	0.30	0.24
32 DE84	0.01	-0.11	-0.01	-0.12	0.12	-0.05	-0.16	-0.07	-0.13	0.06	-0.16	-0.08	-0.10
	0.92	0.36	0.93	0.29	0.30	0.69	0.17	0.57	0.28	0.59	0.18	0.49	0.41
33 DE85	0.13	-0.10	-0.01	-0.07	0.08	-0.07	-0.08	-0.16	-0.11	0.01	-0.07	-0.06	-0.08
	0.28	0.42	0.94	0.54	0.51	0.54	0.51	0.19	0.36	0.93	0.54	0.63	0.50
34 ROA81	0.00	0.01	-0.00	0.13	-0.02	0.15	0.16	0.06	0.09	-0.02	0.08	-0.11	-0.09
	0.99	0.91	0.98	0.28	0.87	0.21	0.17	0.62	0.45	0.85	0.51	0.35	0.47
35 ROA82	-0.11	0.00	0.04	-0.02	-0.03	-0.06	0.10	0.17	-0.05	-0.01	0.06	-0.06	-0.06
	0.34	0.98	0.73	0.88	0.81	0.60	0.41	0.15	0.66	0.97	0.62	0.63	0.63
36 ROA83	-0.06	0.09	-0.10	0.06	-0.11	0.03	0.08	0.12	-0.08	-0.01	0.12	0.05	-0.06
	0.59	0.46	0.41	0.59	0.37	0.79	0.51	0.34	0.50	0.93	0.32	0.70	0.60
37 ROA84	-0.19	0.04	-0.03	0.02	-0.13	0.08	0.01	0.21	0.01	0.01	0.06	-0.02	-0.03
	0.10	0.76	0.81	0.88	0.27	0.52	0.92	0.08	0.93	0.96	0.58	0.87	0.80
38 ROA85	-0.09	-0.06	-0.01	-0.09	-0.27	0.10	0.05	0.15	0.01	0.03	0.15	0.12	0.08
	0.43	0.63	0.92	0.42	0.02	0.39	0.66	0.20	0.90	0.83	0.20	0.31	0.48

26		27	28	29	30	31	32	33	34	35	36	37	38
0.44	1 SCRAM	-0.06	0.24	0.16	0.01	0.08	0.03	0.06	-0.07	-0.08	-0.18	-0.19	-0.21
0.00		0.66	0.08	0.27	0.95	0.56	0.86	0.70	0.61	0.58	0.20	0.19	0.14
0.15	2 SSACTUAM	0.01	0.32	0.04	0.03	0.07	0.12	-0.01	-0.16	-0.18	-0.23	-0.21	-0.18
0.20		0.96	0.01	0.76	0.82	0.53	0.32	0.91	0.19	0.14	0.05	0.07	0.13
-0.08	3 SIGEVENT	-0.06	0.11	0.19	0.01	0.14	0.11	-0.02	-0.23	-0.33	-0.46	-0.28	-0.24
0.51		0.64	0.35	0.11	0.96	0.25	0.35	0.89	0.06	0.00	0.00	0.02	0.05
-0.22	4 SSFAILM	0.20	0.14	-0.02	-0.05	0.04	0.15	-0.06	-0.10	-0.10	-0.26	-0.10	-0.08
0.07		0.09	0.24	0.87	0.66	0.77	0.20	0.65	0.42	0.43	0.03	0.40	0.51
-0.14	5 CRITHRM	-0.19	-0.20	0.02	0.00	-0.08	-0.10	-0.03	0.03	0.11	0.14	0.12	0.12
0.24		0.12	0.10	0.88	0.997	0.50	0.43	0.77	0.81	0.36	0.24	0.33	0.32
-0.10	6 FOROUTAGE	-0.05	0.14	0.19	0.11	0.11	0.18	0.11	-0.19	-0.28	-0.23	-0.19	-0.24
0.41		0.70	0.24	0.11	0.37	0.35	0.14	0.36	0.11	0.02	0.05	0.11	0.04
-0.08	7 OUTRATEM	0.06	0.09	0.02	0.01	0.09	0.10	0.08	-0.07	-0.09	-0.11	-0.11	-0.07
0.50		0.60	0.44	0.87	0.91	0.44	0.39	0.49	0.58	0.45	0.34	0.36	0.55
-0.09	8 SALPTOT5	0.40	0.42	-0.00	-0.09	0.10	0.11	-0.09	-0.14	-0.20	-0.22	-0.11	-0.14
0.47		0.00	0.00	0.98	0.55	0.48	0.42	0.53	0.33	0.15	0.11	0.45	0.31
-0.06	9 PLANTSIZ	0.35	0.51	0.04	-0.05	0.08	0.08	0.01	-0.03	0.01	-0.10	0.02	0.05
0.63		0.00	0.00	0.74	0.69	0.49	0.49	0.93	0.81	0.91	0.40	0.88	0.65
-0.06	10 BABWIL	-0.17	-0.22	0.10	0.08	0.12	0.09	0.07	0.05	0.06	0.10	0.10	0.04
0.60		0.15	0.06	0.39	0.51	0.30	0.43	0.58	0.67	0.60	0.42	0.41	0.71
-0.03	11 COMBENG	-0.07	-0.00	-0.12	-0.09	-0.00	-0.07	-0.12	0.05	0.18	0.13	0.23	0.21
0.80		0.56	0.99	0.30	0.45	0.98	0.56	0.30	0.69	0.13	0.26	0.05	0.07
0.08	12 WESTINGH	-0.05	-0.05	-0.08	-0.20	-0.12	-0.12	0.04	0.05	-0.08	-0.10	-0.08	-0.06
0.48		0.67	0.67	0.49	0.09	0.30	0.29	0.71	0.70	0.48	0.39	0.47	0.59
	13 NORTHEAS	-0.10	-0.13	0.19	0.17	0.21	0.12	-0.01	-0.02	0.05	0.03	0.19	0.16
		0.38	0.27	0.10	0.15	0.08	0.31	0.96	0.88	0.67	0.79	0.11	0.17

	27	28	29	30	31	32	33	34	35	36	37	38
14 SOUTH	0.07	0.01	-0.10	-0.17	-0.09	0.01	0.13	0.00	-0.11	-0.06	-0.19	-0.09
	0.55	0.96	0.39	0.14	0.44	0.92	0.28	0.99	0.34	0.59	0.10	0.43
15 MIDWEST	0.14	0.02	-0.09	-0.05	-0.14	-0.11	-0.10	0.01	0.00	0.09	0.04	-0.06
	0.25	0.86	0.44	0.70	0.24	0.36	0.42	0.91	0.98	0.46	0.76	0.63
16 WEST	-0.08	0.09	-0.00	0.09	0.04	-0.01	-0.01	-0.00	0.04	-0.10	-0.03	-0.01
	0.50	0.43	0.98	0.46	0.72	0.93	0.94	0.98	0.73	0.41	0.81	0.92
17 AGE	-0.39	-0.52	-0.09	-0.05	-0.12	-0.12	-0.07	0.13	-0.02	0.06	0.02	-0.09
	0.00	0.00	0.47	0.70	0.31	0.29	0.54	0.28	0.88	0.59	0.88	0.42
18 NOPLANTS	0.22	0.07	0.07	0.02	0.02	0.12	0.08	-0.02	-0.03	-0.11	-0.13	-0.27
	0.06	0.56	0.53	0.84	0.87	0.30	0.51	0.87	0.81	0.37	0.27	0.02
19 NOMAJV81	-0.06	0.04	-0.11	-0.08	-0.01	-0.05	-0.07	0.15	-0.06	0.03	0.08	0.10
	0.64	0.72	0.38	0.49	0.93	0.69	0.54	0.21	0.60	0.79	0.52	0.39
20 NOMAJV82	-0.04	0.08	-0.19	-0.15	-0.13	-0.16	-0.08	0.16	0.10	0.08	0.01	0.05
	0.71	0.50	0.10	0.20	0.28	0.17	0.51	0.17	0.41	0.51	0.92	0.66
21 NOMAJV83	0.12	0.07	-0.09	-0.14	-0.08	-0.07	-0.16	0.06	0.17	0.12	0.21	0.15
	0.32	0.55	0.47	0.24	0.51	0.57	0.19	0.62	0.15	0.34	0.08	0.20
22 NOMAJV84	-0.02	-0.00	-0.23	-0.17	-0.15	-0.13	-0.11	0.09	-0.05	-0.08	0.01	0.01
	0.85	0.98	0.06	0.15	0.22	0.28	0.36	0.45	0.66	0.50	0.93	0.90
23 NOMAJV85	0.55	0.22	-0.00	-0.03	0.03	0.06	0.01	-0.02	-0.01	-0.01	0.01	0.03
	0.00	0.07	0.98	0.81	0.79	0.59	0.93	0.85	0.97	0.93	0.96	0.83
24 LER81	0.00	-0.04	-0.26	-0.29	-0.24	-0.16	-0.07	0.08	0.06	0.12	0.06	0.15
	0.98	0.74	0.03	0.01	0.04	0.18	0.54	0.51	0.62	0.32	0.58	0.20
25 LER82	0.39	0.17	-0.14	-0.19	-0.12	-0.08	-0.06	-0.11	-0.06	0.05	-0.02	0.12
	0.00	0.15	0.24	0.12	0.30	0.49	0.63	0.35	0.63	0.70	0.87	0.31
26 LER83	0.44	0.15	-0.08	-0.22	-0.14	-0.10	-0.08	-0.09	-0.06	-0.06	-0.03	0.08
	0.00	0.20	0.51	0.07	0.24	0.41	0.50	0.47	0.63	0.60	0.80	0.48
27 LER84	1.00	0.51	0.07	0.01	-0.00	0.06	-0.07	-0.22	-0.08	-0.12	-0.07	-0.05
	0.00	0.00	0.55	0.96	0.99	0.62	0.53	0.06	0.51	0.32	0.54	0.68

38
-0.09
0.43
-0.06
0.63
-0.01
0.92
-0.09
0.42
-0.27
0.02
0.10
0.39
0.05
0.66
0.15
0.20
0.01
0.90
0.03
0.83
0.15
0.20
0.12
0.31
).08
).48
).05
).68

	27	28	29	30	31	32	33	34	35	36	37	38
28 LER85	0.51	1.00										
	0.00	0.00										
29 DE81	0.07	0.12	1.00									
	0.55	0.31	0.00									
30 DE82	0.01	0.25	0.80	1.00								
	0.96	0.03	0.00	0.00								
31 DE83	-0.00	0.21	0.78	0.90	1.00							
	0.99	0.08	0.00	0.00	0.00							
32 DE84	0.06	0.24	0.71	0.86	0.93	1.00						
	0.62	0.04	0.00	0.00	0.00	0.00						
33 DE85	-0.07	-0.03	0.37	0.40	0.44	0.56	1.00					
	0.53	0.80	0.00	0.00	0.00	0.00	0.00					
34 ROA81	-0.22	-0.28	-0.58	-0.60	-0.56	-0.65	-0.31	1.00				
	0.06	0.02	0.00	0.00	0.00	0.00	0.01	0.00				
35 ROA82	-0.08	-0.15	-0.53	-0.46	-0.45	-0.53	-0.20	0.76	1.00			
	0.51	0.22	0.00	0.00	0.00	0.00	0.09	0.00	0.00			
36 ROA83	-0.12	-0.21	-0.47	-0.40	-0.49	-0.56	-0.19	0.73	0.82	1.00		
	0.32	0.08	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00		
37 ROA84	-0.07	-0.17	-0.38	-0.36	-0.30	-0.45	-0.60	0.64	0.65	0.65	1.00	
	0.54	0.14	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	
38 ROA85	-0.05	-0.10	-0.34	-0.27	-0.19	-0.34	-0.31	0.52	0.55	0.55	0.80	1.00
	0.68	0.41	0.00	0.02	0.11	0.00	0.01	0.00	0.00	0.00	0.00	0.00

NRC FORM 335 (2-89) NRCM 1102, 3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

(See instructions on the reverse)

1. REPORT NUMBER (Assigned by NRC, Add Vol., Supp., Rev., and Addendum Numbers, if any.)

NUREG/CR-5437

2. TITLE AND SUBTITLE

ORGANIZATION AND SAFETY IN NUCLEAR POWER PLANTS

3. DATE REPORT PUBLISHED

MONTH	YEAR
May	1990

4. FIN OR GRANT NUMBER

D2084

5. AUTHOR(S)

A. MARCUS, M. NICHOLS, P. BROMILEY, J. OLSON
R. OSBORN, W. SCOTT, P. PELTO, J. THURBER

6. TYPE OF REPORT

TECHNICAL

7. PERIOD COVERED *(Inclusive Dates)*

8. PERFORMING ORGANIZATION — NAME AND ADDRESS *(If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)*

STRATEGIC MANAGEMENT RESEARCH CENTER
271 19TH AVENUE SOUTH
MINNEAPOLIS, MN 55455

9. SPONSORING ORGANIZATION — NAME AND ADDRESS *(If NRC, type "Same as above"; if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)*

Division of Systems Research
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555

10. SUPPLEMENTARY NOTES

11. ABSTRACT *(200 words or less)* Perspectives from industry, academe, and the NRC are brought together to develop a logical framework that links organization factors and safety in nuclear power plant performance. The framework focuses on intermediate outcomes which can be predicted by organizational factors, and which are subsequently linked to safety. The intermediate outcomes are efficiency, compliance, quality, and innovation. The organization factors can be classified in terms of environment, context, organizational governance, organizational design, and emergent process. Initial empirical analyses were conducted on a limited set of hypotheses derived from the framework. One set of hypotheses concerned the relationships between efficiency, measured by critical hours and outage rate, and safety, measured by 5 NRC indicators. Results of the analysis suggest that critical hours and outage rates and safety, as measured in this study, are not related to each other. Hypotheses were tested concerning the effects on safety and efficiency of utility financial resources and the lagged recognition and correction of problems that accompanies the reporting of major violations and licensee event reports. Results suggest that both financial resources and organizational problem solving/learning have significant effects on the outcome variables when time is properly taken into account.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*

Organization
Safety
Performance Indicators
Learning
Intermediate Outcomes

13. AVAILABILITY STATEMENT

Unlimited

14. SECURITY CLASSIFICATION

(This Page) Unclassified

(This Report) Unclassified

15. NUMBER OF PAGES

16. PRICE

NRC FORM 335 (2-89)