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Organizational Analysis and Safety for Utilities with Nuclear Power Plants

An Organizational Overview

Prepared by R. N. Osborn, J. Olson, P. E. Sommers, S. D. McLaughlin,
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Pacific Northwest Laboratory
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ABSTRACT

A review of the generic organization literature is focused into a model outlining key relationships among organizational factors and nuclear power plant safety. Volume I of the report contains an overview of the literature. Volume II provides a more detailed analysis of those organizational factors which are expected to be associated with measured indicators of plant safety.

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Richard N. Osborn
Seattle

ORGANIZATIONAL ANALYSIS AND SAFETY FOR UTILITIES WITH NUCLEAR POWER PLANTS

EXECUTIVE SUMMARY

PURPOSE AND SCOPE

This two-volume report presents the results of initial research on the feasibility of applying organizational factors in nuclear power plant (NPP) safety assessment. A model is introduced for the purposes of organizing the literature review and showing key relationships among identified organizational factors and nuclear power plant safety. Volume I of this report contains an overview of the literature, a discussion of available safety indicators, and a series of recommendations for more systematically incorporating organizational analysis into investigations of nuclear power plant safety. Volume II provides a more detailed analysis of those organizational factors we expect will be related to measured indicators of plant safety.

WHY AN ORGANIZATIONAL ANALYSIS

In an industry dominated by technical concerns, it is logical to ask why one should be concerned with an organizational analysis. There are several reasons.

- Some utility executives, Nuclear Regulatory Commission (NRC) officials, and critics have suggested that organization and management are often <u>root causes</u> for both good and poor performance.

- <u>Experience in management</u> and organization have important performance implications.

- <u>Preliminary analyses</u> suggest potentially important associations between organizational factors and selected safety indicators for current nuclear facilities.

- Some <u>accident postmortems</u> have strongly suggested that inadequacies in management and organization were contributing factors to the occurrence and severity of accidents.

AN ORGANIZATIONAL PERSPECTIVE: A PREVIEW

Three broad categories of potentially relevant variables form the basis for this report: organizational contingencies, intermediate outcomes, and safety indicators.

Organizational Contingencies

Early organizational studies searched for universal processes applicable to all firms. Now many in organizational analysis suggest that different types of success are contingent upon different organizational factors. Initial work in contingency theory suggested that the internal anatomy of the firm should be matched to the size and scope of its operations, the character of the work to be performed, and the environmental pressures facing the company. More recent work has stressed the need to incorporate management philosophy (organizational governance). A more complete discussion of specific organizational factors is found below.

Intermediate Outcomes

Recent work also suggests that organizational factors should be adjusted to the types of success desired. Long-term safety appears to be enhanced to the extent a utility promotes quality, compliance, efficiency, innovation, and employee maintenance (e.g., morale, commitment, retention). These desirable conditions are called intermediate outcomes because they are expected to be prerequisites for safe operation of a nuclear power facility. Specifically, we focus on the capability of a utility to:

(a) emphasize quality with an attention to the unique aspects of the work process

(b) comply with numerous and sometimes conflicting constraints (including regulatory constraints)

(c) produce electricity efficiently

(d) anticipate, identify, and resolve complex problems with innovative solutions

(e) foster employee maintenance.

Safety Indicators

In the near-term, it is important to isolate specific incidences which appear to reflect the "safeness" of particular plants and facilities. While each available individual indicator appears to be flawed in one way or another, all are not deficient in the same way. By utilizing several measures, it appears possible to compensate for the weakness in one indicator by incorporating the strength of a second or third indicator. In this report, ten different indicators are evaluated and a method for building upon the strengths of selected indicators is proposed.

THE IMPORTANCE OF SPECIFIC ORGANIZATIONAL FACTORS

The organizational literature suggests that many potentially important organizational factors may be grouped into four categories: the environment, the context, organizational governance, and organizational design. A brief sketch of each follows.

The Utility's Environment

Environmental factors help shape the performance demands placed on the utility, the resources available to utility managers, and the boundaries for action. While all nuclear utilities may be subject to similar general economic trends and NRC requirements, each also faces a unique set of pressures and conflicting demands. Differences in local setting, state regulators, and support offered by vendors appear to alter the capability of a utility to achieve desired intermediate outcomes. Further, most nuclear utilities are not freestanding, independent firms. They are quasi-autonomous units which are embedded in quite complex ownership and power-sharing networks.

Conflicting external demands on utilities for greater efficiency, safety, and regulatory compliance are becoming more difficult to meet as utilities face a more uncertain, contentious, and highly interdependent socio-economic setting. Building and operating a nuclear power plant has become more than a technical challenge. For example, it appears that:

- If 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 promote quality, innovation, compliance, efficiency, and employee maintenance, thus threatening safety (see Volume I, p. 45).

The Utility's Context (History, Size and Technology)

Utilities are among our largest and oldest institutions. The building of a nuclear facility brings dramatic changes in the size of the organization, its mix of technology, and the sophistication of the process used to generate power. Utilities with a tradition of conservative practices and an attention to sound fiscal management may have difficulty adjusting to a dramatic increase in the number of employees with highly specialized skills. A nuclear facility brings changes in kind, not just in degree, of the demands, constraints, and opportunities facing a utility. For example, it appears that:

- More sophisticated nuclear technology is expected to result in a more diverse organizational design with greater emphasis on quality and administration (see Volume I, p. 47).

- While more sophisticated nuclear technology may yield more emphasis on quality and innovation, it may result in lower efficiency and compliance (see Volume I, p. 47).

- Larger nuclear divisions can take advantage of economies of scale for greater potential efficiency (see Volume I, p. 46).

Organizational Governance (Management Philosophy)

One of the key tasks of top management is to develop, implement, and maintain an overall strategy which allows the utility to recognize and cope with the additional complexity inherent in nuclear operations. The form of organizational governance is a key element underlying the myriad of decisions utility executives must make to successfully operate a nuclear facility. Organizational governance helps define what is important, how issues will be defined, who should (and should not) be involved, plus the range of acceptable alternatives for implementation. A well-designed form of organizational governance permits and facilitates resolution of the competing demands, constraints, and choices facing the nuclear utility.

Three ideal types of organizational governance are useful in analyzing nuclear utilities. A traditional type emphasizes bureaucracy (administrative controls, written policies, elaborate written procedures). A modern type stresses single-set values where individual judgment is to be used to successfully implement policy. A federal type emphasizes negotiation and the integration of several differing views through effective conflict resolution. These various forms of governance suggest several safety relationships. For example:

- The traditional form of governance will be associated with higher efficiency and compliance but lower quality and innovation (see Volume I, p. 48).

- The modern form of governance will be associated with erratic compliance and higher efficiency (see Volume I, p. 48).

- The federal form will be associated with higher quality and innovation, and lower compliance (see Volume I, p. 48).

Organization Design

How the organization is designed (its anatomy) plays an important role in which issues get resolved, which technical skills are developed, what relations with outside technical units will be fostered, and how problems are to be analyzed and prevented. Four aspects of organizational design are emphasized in this report: (a) how work is divided among units and individuals, (b) the nature and types of controls placed on units, managers, and individuals, (c) the mechanisms for coordination, and (d) the developmental mechanisms which foster, reinforce, and direct the actions and decisions of individuals. While each aspect of design appears important, the pattern across these aspects also appears related to intermediate outcomes. Some organizations may select a rigid, machine-like pattern--a mechanistic design, while some may evolve a more fluid professional pattern--an organic design. Due to environmental, contextual, and governance concerns, it appears that nuclear utilities should consider a mix of mechanistic and organic patterns. Such a mix may be called a diverse design. Several example propositions illustrate the potential importance of organizational design:

- More organic organizational designs promote higher quality, innovation, and employee maintenance (see Volume I, p. 50).

- More mechanistic organizational designs promote higher plant efficiency for plants early in their life cycle (see Volume I, p. 50).

- 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 (see Volume I, p. 50).

Combination Effects and New Issues

There appear to be potentially significant combination effects among factors. While these effects may be most difficult to understand, they could well be the most important. For example:

- With greater environmental complexity (sustained over a lengthy period) there will be a shift toward a federal form of governance and a more diverse organizational design (see Volume I, p. 45).

- The larger the nuclear organization, the more mechanistic it is and the less it tends to emphasize quality (see Volume I, p. 46).

- The dysfunctional effects of size on intermediate outcomes may be partially offset by a change toward a federal form of organizational governance and a more diverse organization design (see Volume I, p. 46).

- Utilities with several types of nuclear plants will experience pressure toward a more diverse organizational design (see Volume I, p. 47).

Combination effects raise a series of new issues. Four issues appear particularly important. First is the question of the interdependence among the factors needed for safety. A simple change in one element of one organizational factor (e.g., the addition of a new headquarters staff unit for safety review) suggests a change in an element of another factor (e.g., a revised view of authority--an element of management philosophy). Are both changes needed? Are both desirable? Could the positive safety effects of one change be more than offset by changes in other factors?

A second issue deals with organizational capability. Assuming that changes are desired, are all factors and all elements within each factor subject to change at the same rate and with similar ease? Probably not. Thus, the burden for change is likely to rest more on some organizational factors than others. Presuming that organizational design is easier to change than other factors in the model, design becomes a major mechanism for meeting new demands. However, it may not always be possible for utilities to develop an organizational design which (a) meets new demands, (b) meshes with its existing environment, context, and form of governance, and (c) continues to provide a viable tool for reaching toward quality, compliance, efficiency, innovation, and employee maintenance.

The third issue also deals with capability. It concerns the role of organizational factors in successfully implementing several changes simultaneously. For instance, could a myriad of mandated technical changes, each of which attempts to improve safety, overload the utility's organizational capacity for successful implementation?

A fourth issue centers on how organizational factors may influence other potential safety determinants. For instance, presume the utility cannot develop an organizational design which helps it meet all the inconsistent demands for change. Part of the burden falls on managers and workers. The implications for safety are clear, even if one presumes that utility executives and employees are unusually competent and vigilant. Just as we do not know which atom will split in a chain reaction, we do not know which mistake, oversight, or failure by a particular manager or worker may threaten health and safety. We can expect, however, that as organizational factors place a greater burden on individual managers and workers, the likelihood and severity of error increases.

OVERALL CONCLUSIONS

Preliminary analysis suggests that important organizational factors are associated with several indicators of safety. However, while considerable information on nuclear utilities exists, comparatively little is now in a form which facilitates systematic analysis. Specifically, our analysis suggests that:

(1) Potentially important organizational factors can be measured.

(2) Organizational analyses made by NRC and industry can be made less judgmental by the adoption of a systematic review protocol based on existing organizational knowledge.

(3) Some, if not much, of the existing industry and NRC attention may not now be focused on those organizational factors that are potentially most important for safe operation of a nuclear power plant.

(4) Existing safety indicators are flawed, but appear flawed in quite different ways. It appears possible to develop less biased and more meaningful indicators of safety performance with existing data using a "multiple indicator" approach.

LIMITATIONS

The report constitutes only a first step. While it may provide new insight into the question of nuclear power plant safety, it is not a definitive treatment. We did not uncover any empirical analysis linking organizational factors and the safety of nuclear power plants. Further, organizational analysis is a comparatively new field--one where controversy abounds. Finally, the literature review did not attempt to analyze the extent to which the predictors are amenable to different regulatory strategies.

1. INTRODUCTION

This two-volume report presents the results of initial research on the feasibility of applying organizational factors in nuclear power plant (NPP) safety assessment. In this volume a model is introduced for the purposes of organizing the literature review and showing key relationships among identified organizational factors and nuclear power plant safety. Essentially, we address four questions: Can organizational analysis contribute to the safe operation of a nuclear power plant? If so, which aspects of organization are most important? Could the important aspects be systematically measured and related to safety? What types of information are currently available to initiate an organizational analysis? A model is used to outline key relationships among identified organizational factors and nuclear power plant safety. Volume I of this report contains an overview of the literature. Volume II provides a more detailed analysis of those organizational factors we expect will be related to measured indicators of plant safety.

The bulk of this volume examines what organizational analysis is and is not, what one can usefully examine, and what are the likely patterns of association among organizational factors and safety.* We show that organizational analysis provides an integrated, consistent view of an important part of nuclear operations. We provide a framework that allows one to link theoretical assertions with facts without sole reliance on anecdotal accounts.

In Section 2, there is an overall discussion of the organizational perspective. Section 3 identifies and discusses key organizational characteristics. Here one finds a discussion of the utility's environment, its context (with an emphasis on size and technology), forms of organizational governance, and organizational design. Section 4 introduces a set of intermediate outcomes. These are organizational outcomes which are argued to be preconditions for safe operations. They include quality, efficiency, innovation, and compliance. Section 5 provides a discussion of the concept of safety, with an emphasis on how it might be measured within the nuclear industry for purposes of empirical analysis. Section 6 summarizes the analysis with a series of selected propositions. Finally, Section 7 outlines a series of recommendations for improving organizational assessments by the Nuclear Regulatory Commission (NRC). We begin by discussing why an organizational analysis may be helpful.

2. WHY AN ORGANIZATIONAL ANALYSIS

Utility organization characteristics and processes underlie many of the more obvious deficiencies enumerated in critical analyses of nuclear operations. Poor training, inadequate maintenance, sloppy/confusing/contradictory procedures, questionable quality assurance, marginal staffing, poorly designed and constructed equipment, shoddy workmanship, human error, and inefficient operations each have their own unique causes. However, all share

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*For a different perspective highlighting individual and small-group factors, see Cummings (1982).

common causes in the character of utility management and organization. Alterations in utility management and organization can help prevent these more obvious deficiencies. In a similar vein, the current record of safe operations and attempts to continually improve safety can also, in part, be attributed to utility management and organizational factors. In short, both good and bad performance reflects the management and organization of the utility.

2.1 Evidence of the Need for a New Perspective

Analyses of the Three Mile Island accident (TMI) strongly suggested the importance of utility management and organizational factors (e.g., USNRC, 1979). The following analysis of the literature also supports this contention. NRC, utility, and industry officials themselves agree that utility management is important even as they disagree over which factors are important and whether NRC should develop new regulations in this area (see Widrig et al., 1981). The most recent evidence was developed in conjunction with this project. Namely, in a tentative, limited analysis individual, biased, and limited measured aspects of utility organization were found to be associated with measured safety indicators. Overall, the proportion of variation in safety indicators associated with utility organizational factors was substantial. While such results may not hold under more rigorous analysis, they fit into a pattern. This pattern suggests that the nuclear power industry may benefit substantially from a more comprehensive examination of organizational causes of safe operations.

2.2 Management Versus Organizational Analysis

Many recognize both the underlying importance of utility management and organization and the inherent difficulty of developing effective regulations in management. Less well recognized is an important distinction between management and organizational analysis. Management analysis is frequently concerned with the behavior, decisions, and processes of or attributable to managers taken alone or as a group (e.g., Koontz and O'Donnell, 1955). Organizational analysis, on the other hand, is most centrally concerned with the organizational conditions in which behavior, decisions, and processes occur (e.g., Connor, 1980; Osborn, Hunt, and Jauch, 1981; Scott, Mitchell, and Birnbaum, 1981). While the distinction may appear subtle, it is quite important.

The organization establishes a setting for individual and collective action. Managers operate within a series of boundaries set in part by organizational demands, constraints, and choices. For example, the form of organizational governance (or philosophy, as some utility managers call it) centers attention on a limited number of factors, focuses action, and establishes a basic reward (and sanction) system. The design of the organization outlines the division of labor, specifies the outcomes considered desirable, promotes coordinated action, and facilitates improvement over time. Within the organizational design and under a form of organizational governance, one finds the individual and collective behavior, decisions, and processes of managers. Alterations in organizational governance and design factors can alter managerial decisions, behavior, and processes. That is, a change in demands, constraints, and choices, an alteration in what is considered important, a revision of what the focus of action should be, and/or adjustments in what is rewarded can alter not only how managers do their jobs but also what their jobs are. Finally, organizational analysis does not automatically yield a requirement for the regulator to manage. It may be used to permit managers to utilize their training, experience, and skills with minimal, direct, external interference. This final factor needs to be emphasized. An organizational analysis by external parties does not automatically lead to the regulation of management.

2.2.1 Advantages and Costs of Organizational Analysis

A focus on organizational factors has a number of advantages for the NRC over the more typical emphasis on managers. First, the operating license is given to the utility (not its managers) for some 30 years. While individual managers come and go over the lifetime of the license, the utility is the same. To primarily rest the decision to grant a license on the quality of managers would ignore the length of the licensing period and the legally accountable entity holding the license. Second, analyses of individual managers suggest few, if any, common traits amenable to regulatory action. Third, while a wide variety of management practices may yield approximately equivalent safety, the range of acceptable organizational conditions may be narrower. Fourth, it is more realistic and less expensive to monitor the character of utility organizations than the ongoing behavior, decisions, and processes of individual managers.

Organizational analysis also helps avoid a number of common pitfalls. For example, it stresses an integrated socio-technical, human-machine perspective. Neither equipment alone nor the unusually talented manager need to be the only pillars supporting public safety. A concentration on individual managers, particular techniques, or specific equipment often obscures the underlying reasons for action or the lack of action. Organizations can be designed for average managers much as plants can be designed to account for potential flaws in equipment. Since organizational analysis stresses the interconnections and interdependencies among the human and technical aspects of complex operations, it avoids much of the inherent limitations of narrow, segmented, and partial views. The costs are, of course, much the same as for other insightful perspectives--the time, energy, and resources to study and understand. The reader should not expect simple analogies, easy explanations, and broad generalizations--for an organizational analysis of nuclear operations is as complex as an engineering analysis. Just as a switch from fossil to nuclear yields different and more complex technical questions, it also yields different and more complex organizational ones.

2.3 Lessons from Other Industries

One of the key lessons drawn from an historical analysis of organizations is that the central importance of organizational factors typically emerges far after the development and deployment of a new technology. Initially, one finds a technical logic dominating the organization. Then, often after one or a number of shocks, a new perspective based more on an organizational logic may emerge.

2.3.1 An Emphasis on Technology

Early in the development and deployment of a technology, identifying and resolving technical problems can be expected to dominate other concerns. As major technical questions are identified and adequately resolved, attention often moves toward collateral issues of successful, efficient operation and marginal improvements in equipment and processes. Where competition looms, a shift toward a marketing emphasis is often characteristic of those firms which survive an almost inevitable shake-out period. Historic examples include steel, railroads, radio, and television. The shock of TMI may be a precipitating factor which triggers change much as market factors have in other industries.

2.3.2 Technological Emphasis from the Shop-Floor Up: A Blind Alley

While organizations can rely almost exclusively upon technical expertise to ensure success early in the development and deployment of a new technology, such may not be the case later. Early in this shift toward a more complete and comprehensive view of organizational operations, analyses built upon the basic technology are often used to improve efficiency. Perhaps the most well-known example is the work of Frederick Taylor. Scientific management or, more specifically, work engineering for non-managerial jobs, was a successful approach for the standardization and routinization of repetitive tasks. Much of the lore and common wisdom of operations management stems from refinements and extensions of scientific management (cf., Koontz and O'Donnell, 1955). The emphasis on technical functions (e.g., operations, maintenance, health physics) within the plant by the Institute of Nuclear Power Operations (INPO, 1981) is suggestive of this approach applied to the nuclear industry.

Many managerial techniques and perspectives which are extensions of the basic technology are developed at or near the shop floor, and they appear quite useful to lower-level managers since they address improvements in the functional requirements placed on supervisors. These techniques and perspectives may become institutionalized as junior executives rise to top management. However, the focus on technical functions to explain and predict organization performance has generally not been supported in the literature (Blau, Falbe, McKinley, and Tracy, 1976). Since analysis of functions appears quite popular in the nuclear industry (e.g., INPO, 1982), some additional discussion seems warranted.

A concentration on specific functional areas appears most consistent with a technological determinist perspective of organizational operations. Specifically, the argument is that the character of the dominant technology should determine the most appropriate formal structure (cf., Woodward, 1965). The emphasis on "functional" areas which match particular academic or applied disciplines is one variation of technological determinism which one may expect to find early in the deployment of a new technology and which is likely to be an enduring feature deep within complex organizations (e.g., Burack, 1975).

On the surface, it would appear that such a functional emphasis can be expected for the supervisory level activities in nuclear power plants. There are two major versions of the light water reactors, Boiling Water Reactors (BWR) and Pressurized Water Reactors (PWR), which dominate the industry, and but one operating gas cooled reactor in the U.S. under an NRC commercial license. Thus, one would expect an emphasis on those "functions" needed to produce power with either a BWR or a PWR. A list of such functions could emanate from the systems, components, and equipment found in these types of plants with one generic list for all light water reactors and specific lists for PWRs and BWRs.

As appealing as this perspective may be for analysis of units within a plant, literature suggests it is not appropriate for analyses of organization and administration of nuclear operations. First, empirical tests of the functional perspective in a variety of settings suggest it does not adequately model actual practice, nor does it appear to provide verifiable explanations or predictions of such intermediate outcomes as quality, compliance, innovation, and efficiency.* Second, nuclear power plants appear to have different technologies embodied within them and safe operation of a nuclear facility appears to draw on many different technological perspectives in combination with each other (see section 3.2.3.2). The integration of these technologies mitigates against a sole reliance on a functional approach. Third, the literature, interviews with utility managers, and analyses of accident postmortems all suggest that organization and administration factors cutting across narrow functional areas may be more important for the long-term safety of nuclear power plants than any one function (e.g., Perrow, 1981). A simple functional analysis suggests that if each separate function is well performed, a plant would be safe. This is inconsistent with numerous analyses of nuclear operations (e.g., Egan, 1982; Perrow, 1981). Fourth, the functional perspective would suggest that experience would yield a most preferred formal structure and series of managerial practices. Such is not the case. Industry structures and practices vary considerably. While critics may cite this as evidence of a lack of management concern for safety functions, we suggest it simply confirms prior research findings. Organizational dynamics are simply <u>not</u> technically determined.

2.3.3 Fixation on Technology and Human Nature

With growth and a favorable market environment, a technological perspective may persist for decades. An industry may face chronic problems due to the inherent limitation of an exclusive focus on technical factors. Yet, these chronic problems are often attributed to human nature, constraints beyond the control of management or, of course, technological limitations.

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*A central problem with the function view is the variety of definitions and meanings given to the term function. For an extended discussion see Miner, 1982.

The attribution of difficulties to technical factors and seemingly uncontrollable human nature has sufficient plausibility to inhibit the development of other less directly observable explanations. Yet it is common, in other industries, for the emergence of a perspective or a new set of explanations which underlie the more observable technical problems and human mistakes. (See Volume II, Chapter 4 for discussion of the regulatory experiences in other industries.)

2.3.4 Shocks and a New Perspective

One or more shocks to an industry or key organizations in an industry would be expected to trigger the emergence of a new perspective. In the case of the black powder and chemical industry, it was accidents (see the example of DuPont in Appendix A Chapter 2, Volume II). In the banking industry, it was the Great Depression. The perspective may involve several factors unique to the industry and initially focus on financial, marketing, operational, or ownership changes.

Often an element in the new perspective is a recognition that management and/or organizational concerns are important. Further, a managerial and/or organizational perspective may be used to redefine problems and opportunities. The roots of the older technological thrust may not be a basis for the new perspective. For instance, during the 1960's consumer products manufacturers were under intense competition and a few of the more aggressive firms developed the "marketing concept." Here key choices (type of product, channels of distribution, pricing, and product life cycle questions) were to be driven by the logic of the market rather than the logic of production. Marketing management emerged as a key to the growth and profitability of these organizations. A parallel stressing financial management may be found in the emergence of conglomerates.

2.3.5 Lessons for the Nuclear Industry

A common element in the new perspectives developed in other industries is the recognition of more fundamental and underlying causes which cannot be directly and definitively linked to individual technical functions. Instead of working from technically identified problems or functions back toward causes, the perspective shows patterns which predict and/or precede success and failure. Explanations of why a pattern is successful follow the logic of the new perspective--not the logic of technological determinism.

What does this mean for the nuclear industry, the NRC, and other interested parties? TMI was a shock which could be the impetus for a new perspective. This perspective could help identify some of the underlying causes of less than completely safe operations. A fixation on new equipment, better procedures, advanced systems, and retrofitting, however, could stymie the development of a more comprehensive view. If the lessons of other industries are to be applied, one may begin by charting an organizational perspective. Once charted, this new perspective on the nuclear industry may be refined, examined, and empirically tested.

3. ORGANIZATIONAL ANALYSIS AND SAFETY

A logical starting point for an organizational analysis of safety in nuclear power plants would be to provide a definition of safety and then review prior studies of organizational factors and safety. Two problems immediately surface. Safety for a nuclear power plant does not appear to be a concept with one widely shared meaning; it has only a very general meaning and is likely to be estimated in quite different ways. For instance, the discussion in Chapter 6 of Volume II shows that a variety of safety related indicators have been used in analyzing the safety of nuclear plants.

A second serious problem in assessing the linkages among organizational conditions and the safety of the nuclear power industry is that the literature does not address the issue directly. There are no replicated, reliable studies of the nuclear power industry from the organizational perspective. There are also very few organizational level studies of safety within high technology organizations. This severely limits the transfer of predictive statements from the literature and forces reliance on intermediate outcomes which may contribute to safe operations, and which have been examined in the literature.

For purposes of this analysis, then, we will address the relationship between organizational factors and a set of intermediate outcomes: quality, efficiency, innovation, and compliance. As argued in Section 4, these organizational outcomes reflect the organization's ability to pursue the goal of safety. These outcomes have the advantages of being logically, and in some cases, empirically linked to safety, and in addition, are more systematically addressed by the organizational literature.

3.1 Organizational Factors

Figure 1 depicts the four major types of factors we expect will be related to the intermediate outcomes. Essentially, the model depicts a "systems contingency perspective" where conditions in the environment of the utility, its context (history, size, and technology), its form of organizational governance, as well as its organizational design, influence one another and the intermediate outcomes. The figure also shows the expected overlap between the intermediate outcomes and safety indicators. This is discussed later in Section 7 of this volume. In the next section we discuss each of the important factors and chart key expected associations among them and the intermediate outcomes. Our discussion will progress down the far left column and end with a series of propositions.

3.1.1 The Utility Environment

We can begin the analysis with an overview of the utility environment to stress the important fact that there are numerous conflicting demands and constraints placed on utilities with operating licenses. It is important to distinguish among two facets of the environment: (1) the general environment or overall socio-economic-political setting, and (2) the specific environment, or the set of other organizations the utility must deal with in order to survive and grow.

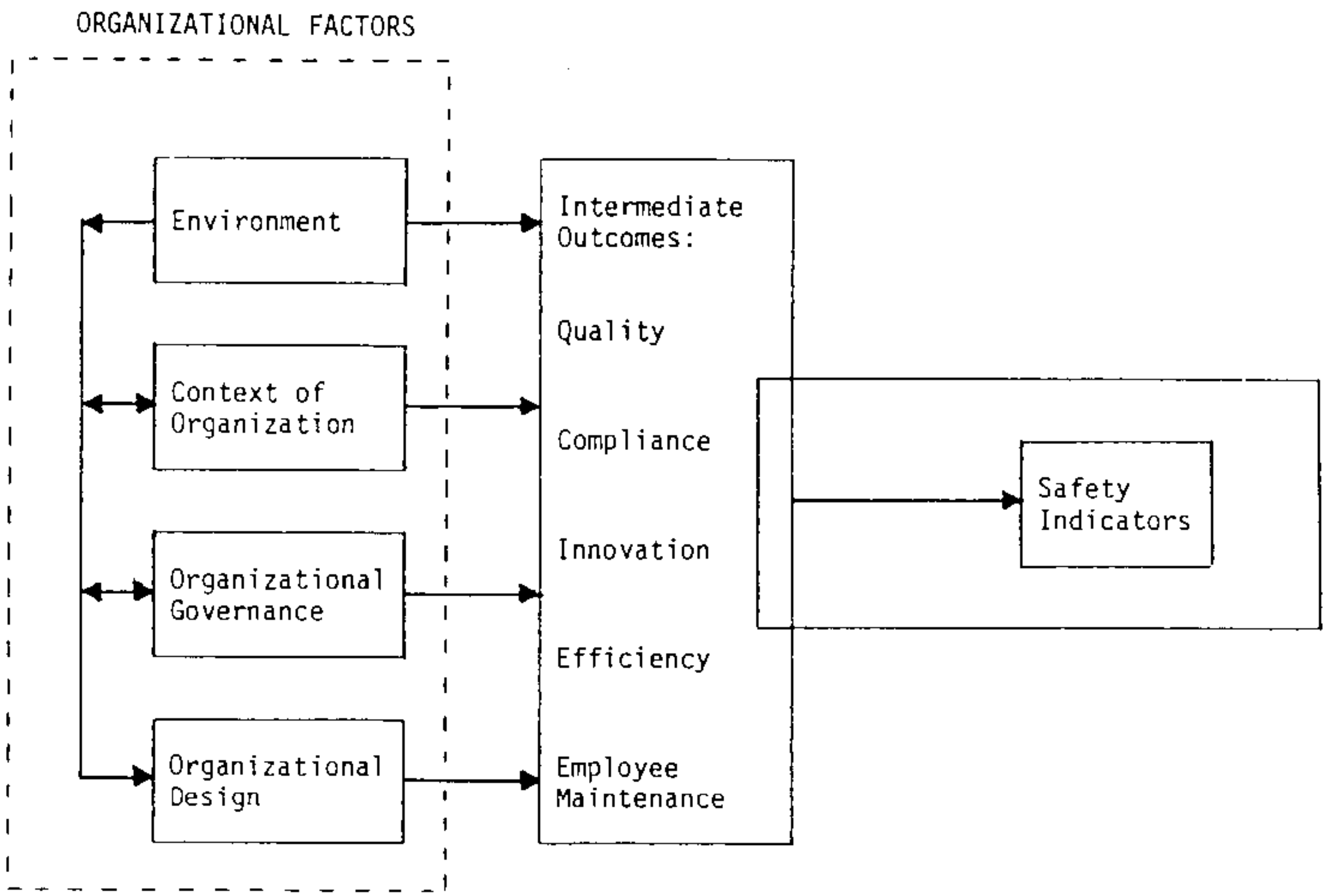

Figure 1. Descriptive Analytical Model of the Relationship of Organizational Factors to Safety

In each section we will be concerned with linking the characteristics of the environment to safety issues--either directly to the intermediate outcomes or through their effects on governance and organizational design.

3.1.1.1 The General Environment

As the title implies, the general environment is the set of economic, legal-political, socio-cultural, and educational forces salient to a particular industry. Socio-economic conditions have not favored nuclear utilities. Recession, inflation, and high interest rates have produced numerous shocks. For example, in less than ten years the apparent need for nine new nuclear generating plants in the Northwest has been cut to three. Rather than detail the substantive changes in the general environment, it appears more useful to note the important, but often unseen, impacts conditions in the general environment have on utilities.

Unanticipated change is perhaps the most dysfunctional force utilities have faced in the last ten years. Increased uncertainty in an industry requiring planning horizons of 20-40 years undermines the foundation for systematic investment decision making. Such levels of "uncertainty" may yield dramatic pressures on the manner in which utilities are governed and also makes successful operation of the bureaucratic aspects of the organization problematic (cf., Thompson, 1967). Nuclear utilities, along with many other organizations, must also cope with the current recession. The overall decline of economic activity coupled with historically high interest rates have placed considerable stress on utility management. One would predict that innovation and quality would generally suffer, and that utilities would resist new, externally imposed requirements.

The lack of clear consensus on the future of nuclear power is a particularly salient feature of the general environment. From the mild concerns of the 1960's to the concerted attempts to block the development of nuclear power in the 1970's and 1980's, utility executives have seen first-hand the costs of societal controversy. The siting and construction of a nuclear facility has become as much a political challenge as a technical one.

With the controversy over nuclear power moving ever more into the political arena, the overall effect may be to direct attention away from operations. Whether the dysfunctional effects of such a controversy on the organizational aspects of the utility have been offset by the discovery and resolution of technical and administrative problems is an open question. It is clear, however, that nuclear utilities face a contentious environment. They are becoming more interdependent with hostile parties.

In sum, the general environment for nuclear utilities has become more risky, with fewer opportunities for growth, and more hostile. Such a more unfavorable setting makes it more difficult for nuclear utilities to engender quality, efficiency, compliance, innovation, and employee maintenance.

3.1.1.2 The Specific Environment

The specific environment of a utility is its set of owners, suppliers, distributors, and regulatory agencies. It appears useful to concentrate on three segments of the specific environment. Namely, there are different patterns of ownership, regulatory constraints, and vendors.

3.1.1.2.1 Ownership and Control

The most obvious distinction in ownership is between public and private. In general, government-owned utilities tend to enjoy somewhat more favorable cost and regulatory conditions than their private counterparts (see Chapter 3 of Volume II). A somewhat more subtle but important aspect of ownership for nuclear operations is the pattern of ownership and control for nuclear plants.

Nuclear plants represent a substantial fixed investment, and utilities have generally limited their risk with inter-utility arrangements. These arrangements range from (a) comparatively loose connections à la coordinating groups, to (b) power pools, to (c) holding company operations where selected nuclear services are shared among several large utility subsidiaries, to (d) joint ventures, to (e) specialized nuclear organizations owned by several independent utilities. As outlined below, the literature would suggest that these different patterns of ownership and control are quite important for organizational governance and perhaps aspects of organizational design. Overall, as the pattern of ownership and control becomes more complex, the nuclear operations become more difficult to manage. Part of this difficulty is attributable to concomitant increases in size, the diversity of operations, and the range of interests to be integrated. An examination of the linkage among ownership patterns and organizational governance illustrates this proposition.

The literature suggests that organizations contain a dominant coalition (cf., Scott et al., 1981). The dominant coalition is often a group of executives at the top of the organization. The nature, character, and dynamics of the coalition is an important feature underlying the pattern of organizational governance for the organization as a whole. A change in the nature, character, and dynamics of a dominant coalition will, then, alter the pattern of organizational governance which in turn can be related to the design of the organization and its intermediate outcomes.

The dominant coalition is expected to systematically change when we move from an independent utility to a power pool to a holding company arrangement. Specifically, the dominant coalition is likely to become more diverse and develop a pattern of governance which both recognizes this diversity and satisfies the competing demands emanating from both within and outside the individual subsidiaries. Nuclear operations may become a comparatively small piece in the overall governance picture. The implication of different types of dominant coalitions for safety is discussed in Chapter 2 of Volume II.

3.1.1.2.2 Regulators

At the federal level, inter-state utilities and holding companies are subject to regulation by the Federal Energy Regulatory Commission (FERC) and the Securities and Exchange Commission (SEC), as well as the Environmental Protection Agency (EPA) and the Nuclear Regulatory Commission. Essentially, state public utility commissions, FERC, and the SEC are concerned with financial matters. They are to protect the public from excessive rates because utilities are granted a monopoly. The NRC and, to a lesser extent, the EPA are predominately interested in questions of public safety. While these two perspectives are generally recognized, the conflicting pressures placed on utilities are often overlooked.

Carolina Power and Light provides a classic example of conflicting regulatory signals. The North Carolina Utilities Commission funded a management audit of Carolina Power and Light (Cresap, McCormick, and Paget, Inc., 1982). With the focus on financial performance, the consulting firm of Cresap, McCormick and Paget, in a report dated December 15, 1982, noted the "need to improve the operating performance of the Brunswick Nuclear Project." The report noted substantial progress by the utility in response to earlier reports and indicated that major improvements had been instituted. Specifically, the report stated, "We believe it (Carolina Power) is now properly postured to return the plant to acceptable operating performance" (page 2). On February 28, 1983, The Wall Street Journal reported that the NRC had fined Carolina Power $600,000 for failure to conduct proper tests at Brunswick. The utility was cited for "poor corporate and facility management controls." While such apparently contradictory evaluations may not be inconsistent (e.g., the periods of evaluation may be different), they appear to reflect the different types of regulatory pressure facing nuclear utilities. It appears some regulatory agencies evaluate nuclear utilities on efficiency without weighting safety heavily, while others stress safety.

3.1.1.2.2.1 NRC as an Influential Regulator

In addition to the uncertainty and the obvious dependence of utilities upon varied regulatory agencies, there is a more subtle form of influence emanating from the NRC. The NRC's general regulatory strategy appears to focus on particular subsystems and components one at a time. Areas identified as potentially affecting safety are subject to isolated analysis (e.g., distinct analyses for QA, health physics, simulators, and training). Once regulations are promulgated, detailed inspection and enforcement of each area can be expected. Inspectors make attributions as to the cause of the lack of conformity (cf., Kim, 1982). As noted above, the failure to conduct certain tests at the Brunswick plant was attributed to poor utility and facility management controls. Examinations of particular areas (see Chapter 5 of Volume II for a description of health physics evaluations) may be based on one or some combination of untested and implicitly stated perspectives of management and organization. To the extent separate evaluations are based on different implicit theories, utility executives are placed in an almost untenable position. If they subscribe to each of the differing implicit theories, they face the difficulty of integrating and coordinating functional areas with quite different forms of administration. If they resist, they are not in compliance. Further, there is no empirical evidence uncovered in this literature review to suggest that the particular form or type of management implied by separate regulation of particular functional areas yields greater public safety. Continuation of the NRC strategy may reduce the utilities' capability to focus on safety.

It is possible that some of the regulations promulgated by state public utility commissions and the NRC may focus attention away from factors which can be empirically linked to indicators of safety. In other terms, the current emphasis on rates by state regulators and the existing NRC strategy do not focus on all of the variables our reading of the organizational literature suggests would be associated with innovation, compliance, quality, and efficiency. The most obvious need is to empirically examine the proposed relationships embodied in this report and focus on those with measured associations with safety indicators.

3.1.1.2.2.2 Self-Regulation

In addition to federal regulators and state public utility commissions, utilities have also subjected themselves to several quasi-independent self-regulatory bodies (e.g., INPO, 1981, 1982). Many also subscribe to American Nuclear Society standards (e.g., ANSI/ANS, 1981). To a greater or lesser degree, such self-regulation protects a utility from direct, detailed surveillance by governmental regulators. Self-regulation also appears to recognize the mutual interdependence among all nuclear utilities. Again, however, self-regulation currently appears to be focused on technical functions.

3.1.1.2.3 Vendors

It is apparent that the Nuclear Steam Supply System (NSSS) vendor plays an important role in the safety of the plant. In addition to the design and fabrication of key parts and equipment, NSSS vendors appear to play an important role in operations. They can provide a range of services, act as a mechanism for sharing information, identify technical problems and recommend solutions, and offer direct assistance to utilities in promoting efficiency and innovation.

There are several key questions concerning the vendors themselves and relations between a vendor and a utility. How long will existing NSSS vendors remain committed to nuclear operations? Is the volume of business in servicing existing reactors (both in the U.S. and abroad) sufficiently large to maintain technical growth within the NSSS vendors? Can particular utilities become over-dependent upon their NSSS vendor? To what extent can vendors provide collections of utilities technical assistance? To what extent can or should vendors work through or with industry groups, such as INPO, to assist utilities?

An analysis of the history, current levels, and types of assistance, as well as the forms of boundary spanning among vendors, utilities, and related suppliers is needed. It is possible that vendors and other suppliers could help provide utilities with a richer, more stable, and more interdependent setting. If so, vendors and other suppliers could help offset some of the more dysfunctional aspects of the utility environment noted above.

3.1.2 The Context (History, Size, and Technology)

As Table 1 shows, nuclear utilities are relatively old and large organizations. Organizations dating to the turn of the century are using some of the most advanced technologies available to the industrial community. The history, size, and character of the utility's technology have received considerable attention in the organizational analysis literature.

3.1.2.1 Size and Intermediate Outcomes

Sheer size has been associated with a number of what we have called intermediate outcomes (see Osborn et al., 1980 for a review). Greater size often facilitates greater productivity and has been associated with less innovation. The linkage between quality and size is indirect. There appear to be somewhat conflicting pressures on quality from greater size. On the one hand, greater size may be a prerequisite to hiring the needed specialists, obtaining specialized equipment, and acquiring necessary financial support. On the other hand, some of the natural consequences of greater size work against a particularistic approach to the work process that characterizes high quality. When comparing small and large organizations, one normally expects to find greater compliance to externally imposed requirements among the large systems. However, huge organizations may systematically attempt to alter the basis for external compliance (change the rules) to ensure that regulators develop compliance programs they can meet. Further, larger organizations are more likely to argue for self-regulation by an industry group they have substantial impact upon.

3.1.2.1.1 Size, Governance, and Organizational Design

When comparing large versus huge organizations, one expects a more complex pattern of organizational governance which permits the interests of a larger number of competing units to be reconciled (cf., Scott et al., 1981). In the largest organizations, the organization may subdivide into quasi-autonomous units. Smaller organizations may combine (e.g., holding companies, power pools) where the combined entity operates under a governance system stressing negotiation and compromise.

The pressures from greater size on the design of the organization are pervasive. They are most clearly seen in the complexity of the design itself. Among organizations with similar environments and technologies, the larger organizations are likely to have more levels of management, more departments, plus more intricate patterns of coordination and control than their smaller counterparts. A greater emphasis on rules, policies, and procedures may also be in evidence and used for general administration, coordination, control, and development. Overall, the larger the organization the more likely it could be more bureaucratic (see Hage, 1980). Exceptions would be expected under some forms of organizational

TABLE 1

SIZE AND AGE OF NUCLEAR UTILITIES

Size (No. of Employees)	Age (Years) 0-20	20-29	30-39	40-49	50-59	60-69	70-79	80+	Total
0-199	0	4	0	0	0	0	0	0	4
200-499	0	0	0	0	0	0	0	0	0
500-999	0	0	0	0	0	0	0	0	0
1,000-4,999	0	0	1	1	5	2	6	7	22
5,000-9,999	0	0	0	2	3	0	4	5	14
10,000+	0	0	0	0	3	2	3	1	9
Total	0	4	1	3	11	4	13	13	49

governance or where there is a wide disparity in the types of products/ services offered by the organization. As we will note later, the pressures from greater size on organizational governance and organizational design are but one confounding factor which works against developing simple rigid prescriptions.

3.1.2.2 Technology

It is beyond the scope of this project to detail all the myriad impacts of technical factors on organizational operations and safety. It is clear that basic distinctions (size of the reactor and type) should be factored out of any empirical analysis of organizational factors and safety. Organizational analysis does, however, suggest a slightly different perspective on technology than engineering or human factors. In broad outline, the degree of sophistication and variability in the technical demands facing the organization needs to be recognized.

3.1.2.2.1 Conflicting Technical Demands

From an organizational standpoint, nuclear operations represent an unusual mix of technological types. On the one hand, plants are designed to emphasize repetitive, routine, and tightly coupled operations which are as much machine controlled as possible. (Thompson [1967] has called this type of technology long-linked.) In this regard, nuclear and fossil technology appear quite similar. Individual discretion and interference are minimized. On the other hand, parts of the nuclear operation call for considerable professional skill and craftsmanship. Exceptions (e.g., LERs) occur with sufficient frequency and may be difficult to analyze. This type of non-routine technology has been called intensive. Here, a concern for the unique aspects of the work process appears to be a prerequisite for safety (cf., Hage, 1980).

These two opposing technical characteristics (long-linked and intensive) pose an interesting organizational problem, particularly for utilities with a long tradition of fossil or hydro generation. Much of the literature suggests that the organization needed for a long-linked technology is quite different than that needed for the intensive type (see Child, 1972; Perrow, 1967; Connor, 1980; Osborn et al., 1980).

For the more routine or long-linked aspects of nuclear operations, an emphasis on compliance can be developed with an organizational design stressing the more classic bureaucratic aspects. For instance, an emphasis on written rules and procedures, tight control of each "functional" area with detailed specifications for desired action, an elaborate monitoring system, and a pre-specified system for rewards and sanctions fits with considerable individual oversight by managers. The structure is machine-like in character and has been called mechanistic in the literature (cf., Burns and Stalker, 1961). Unfortunately, an overreliance upon this "mechanistic" approach may hinder quality because a mechanistic design is not suited to intensive aspects of nuclear operations.

For the more professional and craftsmanship aspects of nuclear operations, the need for quality and innovation quickly surfaces (Perrow, 1967). If the organizational design emphasizes the more mechanistic aspects, the literature suggests there will be problems. More direct control, tighter supervision, and the development of specialized units (e.g., quality control and quality assurance) may be imposed since they are consistent with the more routine, repetitive, and tightly coupled aspects of operations. It is unlikely these changes will help improve quality and innovation over the longer term. A short-term improvement will most likely be followed by a steady long-term decline. Whether this general expectation holds for nuclear operations is a particularly interesting question, since the general thrust of NRC regulation has been to bureaucratize rather than to stress professionalism or craftsmanship.

3.1.3 Environmental and Contextual Conditions: An Overview

U.S. utilities with nuclear plants vary greatly in terms of ownership, size, type of facility, and location. Such variations may be important because the internal dynamics of utilities can be affected by such factors (e.g., Duncan, 1972). Owners include investor-owned and public organizations, holding companies, and a variety of joint ventures ranging from jointly-owned subsidiaries to joint operating agreements with large numbers of participants (e.g., Smith, 1977; Sommers, 1978). Some nuclear utilities are quite large, with several thousand employees and multiple generating plants. Here, a separate nuclear component (division) may emerge. Others are quite small, consisting of just one nuclear plant with a few hundred employees. Here, a nuclear component which is separate from plant operations does not normally emerge.

Differences in environmental conditions and context suggest that there is quite a range of opportunities and constraints facing nuclear utilities. The amount of resources and extent of discretion available to nuclear plant managers may vary greatly from one utility to another as a result of these differences in environmental and contextual conditions. Furthermore, the governance style and particular organization design used within the nuclear component may vary substantially, depending on the type of utility in which the plants are embedded and the external pressures upon that utility. Thus, in examining nuclear organizations, these differences in the external environment and context should be taken into account.

3.1.4 Available Data on Utility Environment and Context

A great deal of data is available from the regulatory agencies and other public sources concerning the general environmental conditions affecting nuclear utilities. Thus, a good deal of research has been done on utility organizations already, particularly from an economic perspective (e.g., Christensen and Greene, 1976; Crew and Kleindorfer, 1979; Hughes, 1971; Komanoff, 1976; Moore, 1975). Research focused specifically on nuclear utilities is less frequent, but the data to carry out empirical investigations are fairly readily available, with some exceptions. Thus, in this area significant research could be carried out to demonstrate empirically the linkages between selected environmental conditions and intermediate outcomes. In addition, given better data on corporate organization design factors, it would be possible to show the range of organization design choices utilized by utilities classified on the basis of environmental conditions (e.g., ownership) and such contextual factors as size.

Three types of publicly available data bases concerning utilities have been identified:

(1) regulatory agencies, including U.S. Department of Energy, Energy Information Administration for utility-wide computerized data bases, and the Security and Exchange Commission 10-K filings

(2) utility annual reports

(3) corporations which sell information in the form of industry manuals or machine-readable data files, such as from Moody's.

Despite this relative wealth of information, little careful research has been done on the reliability, validity, and completeness of various sources of data which are used by researchers. Our comparison of several variables taken from each of the types of data sources identified above suggests that commercial data bases have serious reliability problems, whereas regulatory data may be more accurate due to the legal circumstances surrounding their collection. For research purposes, the Department of Energy's Energy Information Administration plus the Securities and Exchange Commission 10-K submissions and annual reports from the utilities are all likely to be required to develop an accurate and complete data base regarding utility organization. However, these data sources do not tap environmental conditions specific to a particular utility, nor do these sources always provide detailed information specific to a particular plant facility.

3.1.5 Organizational Governance

Many utility executives talk of management philosophy to help explain diversity in the nuclear industry. In the literature, the term organizational governance is often used. Earlier we discussed the functions and overall importance of organizational governance. Here we will more carefully define the concept, outline key dimensions, and note three ideal types useful for the analysis of nuclear utilities.

Organizational governance refers to the pattern of authority, influence and managerial behavior desired by the dominant coalition (i.e., top management).* Since nuclear operations have been infused into existing

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*The dominant coalition may extend beyond top managers (e.g., a member of the board of directors) and only a handful of top managers may be members. For simplicity, however, we will use top management in describing the dominant coalition.

institutions, it also appears helpful to discuss a second influential group. This second group is the set of key decision makers for nuclear operations.

First, we reiterate a few key points. Recent analyses of complex organizations suggest that they are as much political systems as administrative or technical entities (e.g., Scott et al., 1981). They must deal with the authoritive allocation of resources and thus with the basic questions of power. Who gets resources, when should they be applied, where should they be deployed and why should power be allocated as it is? It appears that such choices are not made individually but as part of an overall pattern--a pattern established by the dominant coalition. Thus the pattern serves as an underlying rationale for many judgments. And while such patterns of governance or management philosophy may not be in written form, their influence on the organization is substantial.

3.1.5.1 Dimensions of Organizational Governance

Based on the work of Scott and his colleagues (Scott, Mitchell, and Peery, 1981; Scott et al., 1981), it is possible to chart a series of key dimensions for organizational governance and develop consistent generic types from profiles across these dimensions. Specifically, one can examine (1) the power motives encouraged by top management, (2) the character of desired behavior by subordinate managers, (3) the constraints placed on individuals, (4) the purpose of the hierarchy, (5) the view of authority and accountability, and (6) the emphasis placed on participation. While each utility is likely to have its own unique form of organizational governance, it is easiest to explain these dimensions by focusing on three forms. Table 2 lists these dimensions and provides key terms characterizing each dimension for each of the three generic types. The three forms or generic types are called traditional, modern, and federal.

3.1.5.2 Hallmarks of the Three Forms

The hallmark of the traditional pattern is the emphasis on bureaucracy and the bureaucratic aspects of management as hard-won lessons of experience. Here, for example, one expects a close correspondence between the formal structure and actual practice. Questions of administrative controls, written policies, and procedures are given particular attention. In the modern pattern, the emphasis on single-set values stands out. Here application of the values through judgment is to supersede and yet complement bureaucratic processes. In this form, the individual manager, his insight, his experience, and his understanding of how the ideology applies is valued. A third form of organizational governance, the federal, is most easily recognized by the extensive use of negotiation. With the federal form one is likely to hear concern with communication, integration, and the effective resolution of conflict. Three different views of authority and accountability can serve as an example of how these governance forms vary. (A complete description is found in Chapter 2 of Volume II.)

TABLE 2

FORMS AND OIMENSIONS OF ORGANIZATION GOVERNANCE

Dimension	Form		
	Traditional	Modern	Federal
Power Motives	Control (coercion)	Ideological (normative)	Influence (utilitarian)
Constraints Placed on Individuals	Chain of Command and Bureaucracy	Internalization of Single-Set Values	Professional Standards
Purpose of the Hierarchy	Maximize Prescription to Preset Processes	Maximize Prescrip- to Ideology	Maximize Interaction and Coordination
View of Authority/ Accountability	By Position and Centralized	By Individual and Centralized	Multiple and Decentralized
Emphasis on Participation	Low	Low--Some Staff Input	High

3.1.5.2.1 Authority/Accountability in the Traditional, Modern, and Federal Forms: An Illustration

Throughout the existing NRC work on management and embodied in much of INPO's efforts is an emphasis on authority and accountability (also called responsibility by some). The concept of authority plays an important role in organizational governance. First, it is important to understand that authority may be seen as having several sources. It may be viewed as a positional, individual, or a collective notion. And, of course, there is considerable disagreement on whether it is inherently vested in the top, middle, or bottom of the organization. Top management's view of authority and accountability would not normally include the entire range of options. As organizational elites they would naturally see authority as emanating from the top of the organization. The differences which one would expect across the three forms of organizational governance are: (1) the view that authority should be centralized, divided only by functional expertise, and vested in individual positions (in the traditional form), (2) the view that accountability is often shared but authority still remains vested in the senior line manager as both a personal figure in command and the representative of higher authority (the modern form), and (3) the view that authority is inherently multiple, shared, and in part dependent upon acceptance by subordinates (the federal form). This aspect of organizational governance is particularly important for the NRC. The NRC often uses a very simple notion of authority and accountability based on the line chain of command (e.g., the plant manager is responsible) or particular functions (there should be a particular department which is to perform a particular function such as health physics, quality assurance, or operations). Such a view may run quite contrary to that found in some utilities. If so, one would expect utility managers to complain vehemently that NRC was overloading plant managers and functional unit heads.

3.1.5.3 Interfaces among Utility and Nuclear Patterns

One of the more interesting but unexplored areas is the interface between nuclear operations and the management of the utility as a whole. The gap between middle management, particularly operations management, and top management has been alluded to several times in NRC postmortems. The NRC expects top management support for safe operations of nuclear power plants and has indirectly elevated middle management positions toward the top of utilities. NRC expects to find a Vice President of Nuclear at or near the top of the utility (NUREG-0731). Further, nuclear utilities are required to have a corporate nuclear safety oversight committee (or its equivalent). Merely elevating a particular post into top management or requiring a committee does not insure an appropriate interface between top management and nuclear operations, however.

A gap between nuclear operations and utility top management is to be expected. Commercial nuclear operations are comparatively new. Nuclear facilities are, at the same time, technically similar to fossil plants and yet fundamentally different. It is possible that similarities may be overdrawn. Further, top management has many priorities--the safety of a nuclear facility is only one. The result of these factors is clear.

Overall utility policies may be inconsistent with the needs of the nuclear units. If there are also differences in governance it may be difficult for those in the nuclear units to craft a unique safety program. As the DuPont experience suggests (see Appendix A of Chapter 2, Volume II), a safety program consistent with the overall governance pattern of the organization is most likely to receive the attention and resources needed.

Many senior nuclear executives most likely received their early management experience outside commercial nuclear operations. Further, by NRC requirements, the background of these executive-engineers is likely to include either extensive work within fossil operations or the Navy nuclear program. These two historical roots for senior nuclear executives and the overriding importance of technical affairs is likely to yield either a traditional (for those with fossil experience) or a modern (for those with Navy nuclear experience) pattern. It is unlikely that a federal form would be seen in nuclear operations. However, some environmental conditions and complex ownership patterns favor a movement toward the federal form. Whether different patterns of governance for the utility as a whole and its nuclear operations poses a problem is, in part, dependent upon the organizational design selected by the utility.

In sum, the introduction of nuclear operations provides technical, administrative and governance challenges to utilities. While the technical aspects have received considerable attention, the NRC needs to recognize that organizational governance is another important underlying factor. While NRC may be unable to regulate organizational governance, it needs to recognize its character and importance for the successful implementation of its regulations and guidelines and, thus, public health and safety. Of course, there is also the administrative challenge. This is the topic of the next section.

3.1.6 Organizational Design

Organizational design refers to the manner in which the organization structures its activities to solve a set of universal problems. The problems most relevant to nuclear utilities appear to be: (a) how to divide the work and group activities, (b) how to insure that intended actions and outcomes are achieved, (c) how to integrate the activities and outcomes of different units, and (d) how to assure future success. The design dimensions associated with these issues may be called: (a) administration, (b) control, (c) coordination, and (d) development. First we examine these four dimensions and then patterns across these four dimensions.

3.1.6.1 Dimensions of Organizational Design for Nuclear Utilities

3.1.6.1.1 Administration

Administration refers to the way that work is divided up and carried out in the organization. Often writers refer to this aspect of organizational design as the division of labor (Hage, 1980). Administration may be examined in terms of form, but it is also apparent that procedures, individuals, and external resources are used as mechanisms to effectively divide the total job into meaningful parts.* The form of administration refers to the division of work into separate units (departments, divisions, etc.), and the position of each of these in the overall vertical and horizontal scheme of the organization. Administrative procedures are often used to specify the conduct of the work itself. Individuals (with their unique skills and qualifications) are frequently given specific duties and responsibilities. Finally, external resources and constraints (such as corporate technical staff units) available to a unit being studied are important. These external resources and constraints help define the conduct of work within the unit but originate from outside or at a higher level of the organization.

3.1.6.1.2 Control

Control refers to the process whereby the behavior of the organization's members is brought in line with existing standards of conduct (cf., Osborn et al., 1980). It also can be examined in terms of form, procedures, individuals and external factors. Form of control refers to the structure of the formal hierarchy within which power, authority, and influence are exercised. Control procedures refer to rules governing the behavior of members (as opposed to the conduct of work). Individuals, in this context, refers to the rewards and sanctions used to control individuals. A key question in analyzing the role of individuals is, who sets standards, measures performance and dispenses rewards/sanctions? External constraints include such factors as regulatory standards and corporate budgets.

3.1.6.1.3 Coordination

Coordination refers to the efforts of the organization to mesh or integrate the activities of the different parts of the organization into a cohesive whole. Because the activities of various parts of the organization have input and output effects on each other, coordination is often a central concern of organizational design (e.g., Child, 1972). The form of coordination refers to the formal mechanisms that are established to link activities. Examples are standing committees, linkages through the formal structure, matrix organizations, staff meetings, and the like. Coordinating procedures pertains to rules that purposively link the activities of disparate units in the organization. Individuals, in this context, concerns the formal coordinating activities expected of individuals as well as systems designed to assure the participation of individuals in the organization as a whole (e.g., participatory management). External factors relevant to coordination may involve the role of corporate units in linking

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*One may emphasize the form, procedures, individual or external aspects of organizational design. Here one may make a more direct linkage to the literature in terms of bureaucracy (form), formalization and standardization (procedures), plus participation and centralization/decentralization (role of individuals). The degree of diversity (mix of organic and mechanistic) is discussed in the literature under the term complexity.

functions within the plant, the role of professional societies, and the role of external, consultive bodies (e.g., Institute of Nuclear Power Operations) in providing coordination.

3.1.6.1.4 Development

Development refers to the strategic problem of planned change (cf., Litterer, 1973). The forms used to promote change include the existence, nature, and location of organizational units concerned with organizational development (e.g., planning units and training). Procedures refer to the rules that exist to promote development. Individuals refer to incentives and programs designed to encourage individual involvement in development activities. External constraints and resources for the development of a unit in a plant would include the training programs available to the organization and the resources allocated to the units for development purposes.

3.1.6.2 Patterns Across the Issues

Organizations vary considerably in the way they address the four strategic issues of administration, control, coordination, and development. A major thesis of many examining organizational design is that such variation is significant for the overall success of the organization, including safety issues. We will illustrate the importance of these strategic problems by contrasting two generic types of organizations often cited in the literature--the mechanistic and the organic (see Burns and Stalker, 1961). These forms represent significant contrasts on each of the dimensions of administration, control, coordination, and development. The tendency of different parts of an organization toward one or the other is expected to alter its ability to achieve intermediate outcomes. We also introduce the diverse type since parts of the utility are likely to be organic while others mechanistic. (See Chapter 1 of Volume II for more detail.)

3.1.6.2.1 The Mechanistic Pattern

In a mechanistic pattern, administration would lean heavily toward extensive vertical specialization (many levels of management) with narrow tasks where each department would be treated as a separate functional area. This would be backed up with extensive use of written rules and procedures for defining individual roles and prescriptions, a de-emphasis of individual discretion, and minimal expectation of external support. Efforts for control would receive considerable attention. Subscription to procedures and written directives would be used more than individual accounts of events. Coordination would be subordinated to control and would be exercised through the line managers. Written protocols may be used to channel coordination (e.g., a schedule and detailed agenda would be used in meetings among subordinates) with little emphasis placed on direct contact between managers in different functional areas. Line managers would be expected to measure performance, define problem areas, and dispatch remedies when performance was considered below a pre-set standard. (Average performance would be expected and below average performance would be subject to sanctions according to a prescribed and predetermined written policy.) Development in the mechanistic pattern would follow upon evaluations of technically necessary training. As before, such activities would follow written rules and procedures with minimal discretion given to those whose written job description specified a training function. External support for development would only be used in instances of a clear and present need.

3.1.6.2.2 The Organic Pattern

The organic pattern is quite different (Burns and Stalker, 1961). Here one expects to find less vertical specialization (e.g., fewer levels) and more emphasis on integration across the organization. Individuals would be given more discretion as there would be less reliance upon written rules and procedures. There would be more extensive collection of staff groups and perhaps a matrix organization would be developed. Coordination would be stressed over control and extensive emphasis on individual growth and development would be expected. One would expect more emphasis on individuals and external support than on bureaucratic procedures.

3.1.6.2.3 Diversity

For nuclear utilities one may expect to find a mix of mechanistically and organically structured units. This can be called a diverse pattern. Given the character of the technology, the size range in nuclear utilities, the broad geographical spread of nuclear facilities, and the emphasis on plant level regulation by the NRC, we would expect the following:

- Utility formal organizational designs will be more organic than for the plant/facility.
- Where mechanistic and organic units must interface, there will be conflict and misunderstanding unless precautions are taken to buffer the interface.
- Larger utilities with several nuclear plants/facilities will have more diverse organizational designs than smaller utilities with only one plant/facility.

These propositions call for some additional explanation. Greater size and technical diversity (more facilities since each facility is unique) place pressure on organizations to develop more elaborate organizational designs (i.e., more administration, control, coordination, and development). However, NRC regulatory requirements, ANSI/ANS standards and INPO plant assessments place a heavy emphasis on the more mechanistic aspects of plant/facility organization. Thus, these pressures reinforce the traditions of the utility industry--traditions developed over decades of managing comparatively simple, highly routine, and deterministic operations. It is expected utilities will bow to the mechanistic pressures for individual plants and for specific functional areas (maintenance, operations, QA, health physics). But they will also recognize the need for quality and innovation. With sufficient resources (as evidenced by larger size) they will add more organic units to the plant (e.g., safety review units) and reconfigure corporate staff support to cope with exceptions.

3.1.7 Available Data on Organizational Design

The purpose of this section is to briefly describe the nature of the organizational design data that are currently available for analysis. A more detailed discussion of the data sources and the criteria that were used to evaluate them can be found in Chapter 5 of Volume II. The reader is encouraged to consult this chapter.

For this review we investigated nine potential sources of data. They include both NRC and non-NRC sources. Specifically, we investigated the following:

(1) Chapter 13, Final Safety Analysis Report (FSAR) (USNRC, ND_a)

(2) Technical Specifications (USNRC, ND_b)

(3) Quality Assurance Program Reviews from Chapter 17, FSARs (USNRC, ND_a)

(4) Health Physics Appraisal Program Reports (Cunningham, Wigginton, and Flack, 1982)

(5) Edison Electric Institute Nuclear Plant Staffing Survey (EEI, 1980)

(6) Teknekron Evaluation of Utility Management and Technical Resources (Podonsky et al., 1980))

(7) INPO Staffing Survey (INPO, 1981)

(8) INPO Plant Evaluations (INPO, 1982)

(9) Utility Annual Reports

These data sources were selected as having the most potential for allowing a systematic description and evaluation of design characteristics of organizations in the nuclear power industry. (Performance Appraisal Team Assessment Checklists became available as the project was being concluded and are not reviewed here.) Each data source was evaluated on the basis of a set of criteria reflecting reliability, validity, and the coverage of key organizational design characteristics. The data sources were evaluated by asking thirteen questions. The summary name and the questions were:

(1) Accessible: was access to the data possible for analysis?

(2) Systematic: were the data presented in a systematic way?

(3) Parsimonious: were the data primarily relevant to organizational design?

(4) Recent: were the data recent?

(5) Equivalent: were the data collected at equivalent times for all organizations?

(6) Representative: do the data reflect normal operations?

(7) On-line: do the data reflect on-line status?

(8) Consistent: were the data collected in the same way for each organization?

(9) Clear: were instructions for data collection clear?

(10) Replicable: is the data collection approach used replicable?

(11) Accurate: is the data collection technique used accurate?

(12) Corporate: is information available at the corporate level?

(13) Plant: is information available at the plant level?

In addition, each of the data sources was evaluated in terms of its coverage of key aspects of administration, control, coordination, and development. Table 3 summarizes the conclusions of these evaluations for each of the nine sources. In this table the following scale is used:

(1) completely satisfies the criterion

(2) substantially satisfies the criterion

(3) has both positive and negative characteristics relative to the criterion

(4) only slightly satisfies the criterion

(5) does not at all satisfy the criterion.

Table 4 presents an overall evaluation for concept coverage across the range of data sources. Here we examined whether descriptive information could be used to chart how utilities are designed. For instance, in regard to the question of division of labor we asked whether or not the nine sources could answer the following types of questions: (1) is a complete formal table of organization provided (form), (2) are procedures outlining the flow of work enumerated, (3) are individuals mapped onto the formal structure (individuals), and (4) are corporate technical support units for plant operations enumerated (external)? The tables suggest substantial deficiencies in the reliability, validity, and coverage of existing organizational design data on the nuclear industry.

4. SAFETY AND INTERMEDIATE OUTCOMES

Our reading of the organizational literature suggests it is possible to address the issue of safety through intermediate outcomes: products of organizational context, governance, and design that are themselves causative of safety or reflect safety over the life span of the facility (Sutherland, 1977). This focus on intermediate outcomes is favored for four primary reasons. One, nuclear operations are so complex that causal factors are interrelated and, thus, difficult or impossible to identify uniquely. Two, the time horizon for remedial action is such that causes do not yield concrete effects until long after most opportunities for modification have passed. In other terms, there is comparatively little opportunity for instructive learning until after dysfunctional effects have occurred. Three, the consequences of error are inherently too high to tolerate. Four, there have been too few serious accidents to clearly isolate causes from coincidences. These intermediate outcomes include the quality of the organization's operations, its ability to operate efficiently, its ability to innovate and to exact compliance from its members, and the degree of success it experiences in employee maintenance. The position of the intermediate outcomes in our analytical model is given in Figure 2. The relation of each of these to safety is outlined below. (See Chapter 1, Volume II.)

4.1 Safety and Quality

An organizational concern with safety is expected to be reflected in an organizational concern with the process of production itself, since safety reflects the actual work as it is carried out. The importance of this fact lies in the tendency for the organization to be either output oriented or process oriented, but not both. This is an extension of the argument of Perrow (1967) relative to quantity and quality concerns and Etzioni (1975) relative to utilitarian and normative goals.

The link between the construct of safety and concept of quality, then, reflects the organization's relative concern with the work process. This concern is reflected both in a concern with the product, i.e., its uniqueness and complexity (Stinchcombe, 1959; Perrow, 1967), and with the people involved in the productive process, i.e., their inherent worth and centrality to the organization (Lippit, 1982).

This set of linkages is particularly justified for industries, such as the nuclear power industry, where technologies are incomplete--that is, not developed to the point where the parameters and problems of the productive process are known (e.g., Thompson, 1967). Such technologies require primary concern with the productive process, and the problematics of production are also associated with safety risks.

A number of studies have shown that aspects of quality are positively related to indicators of industrial safety through the actions of workers. For example, Seashore, Indik, and Georgopoulos (1960) found that the quality of delivery service was inversely related to the number of reported accidents, while Bell and Telman (1980) obtained a similar set of results in a sample of workers performing rotating shift work. It appears that workers striving for quality are (a) less likely to rush to get a product completed, (b) less likely to be careless, (c) more likely to maintain a clean working environment, and (d) more concerned with the specific technical details of their assigned tasks.

TABLE 3

RATINGS OF NINE POTENTIAL DATA SOURCES ON 17 CRITERIA

Criteria and Content Areas	FSAR	Technical Specifications	Quality Assurance	Health Physics	EEI	Teknekron	INPO Staffing Survey	INPO Evaluations	Utility Annual Reports
1. Accessable	3	2	2	2	5	1	5	5	1
2. Systematic	3	2	3	2	1	1	1	4	4
3. Parsimonious	3	3	4	4	1	1	1	4	4
4. Recent	4	4	3	3	3	4	2	2	1
5. Equivalent	4	4	2	2	2	2	2	3	4
6. Representative	4	3	2	2	2	3	2	3	2
7. On-line	3	3	2	1	1	1	2	2	2
8. Consistent	3	3	3	2	3	3	2	4	5
9. Clear	3	3	3	3	4	3	2	4	4
10. Replicable	2	3		2	4	4	2	4	4
11. Accurate	3	3	2	4	3	3	3	4	2
12. Corporate	4	4	2	4	5	3	3	4	2
13. Plant	2	2	4	3	3	3	2	2	5
Administration									
a. Form	3	3	3	3	2	5	5	4	5
b. Procedures	3	3	3	4	5	4	5	3	5
c. Individuals	3	4	3	3	5	3	3	2	5
d. External	4	5	2	3	5	3	3	5	5
Control									
a. Form	3	3	3	4	3	5	5	3	5
b. Procedures	4	3	2	3	5	5	5	3	5
c. Individuals	3	4	3	4	5	5	5	3	5
d. External	3	3	3	3	5	5	5	4	5

TABLE 3 (continued)

Criteria and Content Areas	FSAR	Technical Specifications	Quality Assurance	Health Physics	EEI	Teknekron	INPO Staffing Survey	INPO Evaluations	Utility Annual Reports
Coordination									
a. Form	3	3	3	4	3	5	5	5	5
b. Procedures	4	5	4	5	5	5	5	5	5
c. Individuals	3	4	3	5	5	3	5	4	5
d. External	5	5	4	5	5	5	5	5	5
Development									
a. Form	2	3	3	4	3	5	3	2	5
b. Procedures	3	3	4	3	5	5	2	2	5
c. Individuals	3	5	5	3	5	4	4	4	5
d. External	2	5	5	3	5	4	3	5	5

1: Completely satisfies the criterion

2: Substantially satisfies the criterion

3: Has both positive and negative characteristics relative to the criterion

4: Only slightly satisfies the criterion

5: Does not at all satisfy the criterion

TABLE 4

OVERALL ASSESSMENT OF DESIGN DIMENSIDN

	Form	Procedures	Individuals	External
Administration	Fair	Fair	Fair	Fair
Control	Fair	Fair	Fair	Poor
Coordination	Fair	Poor	Poor	Poor
Development	Fair	Fair	Poor	Fair

Good = One or more data sources allow measurement on most aspects of the dimension on an organization-wide basis.

Fair = One or more data sources allow measurement on some aspects of the dimension on a significant segment of the organization.

Poor = Measurement is not supported by the data sources.

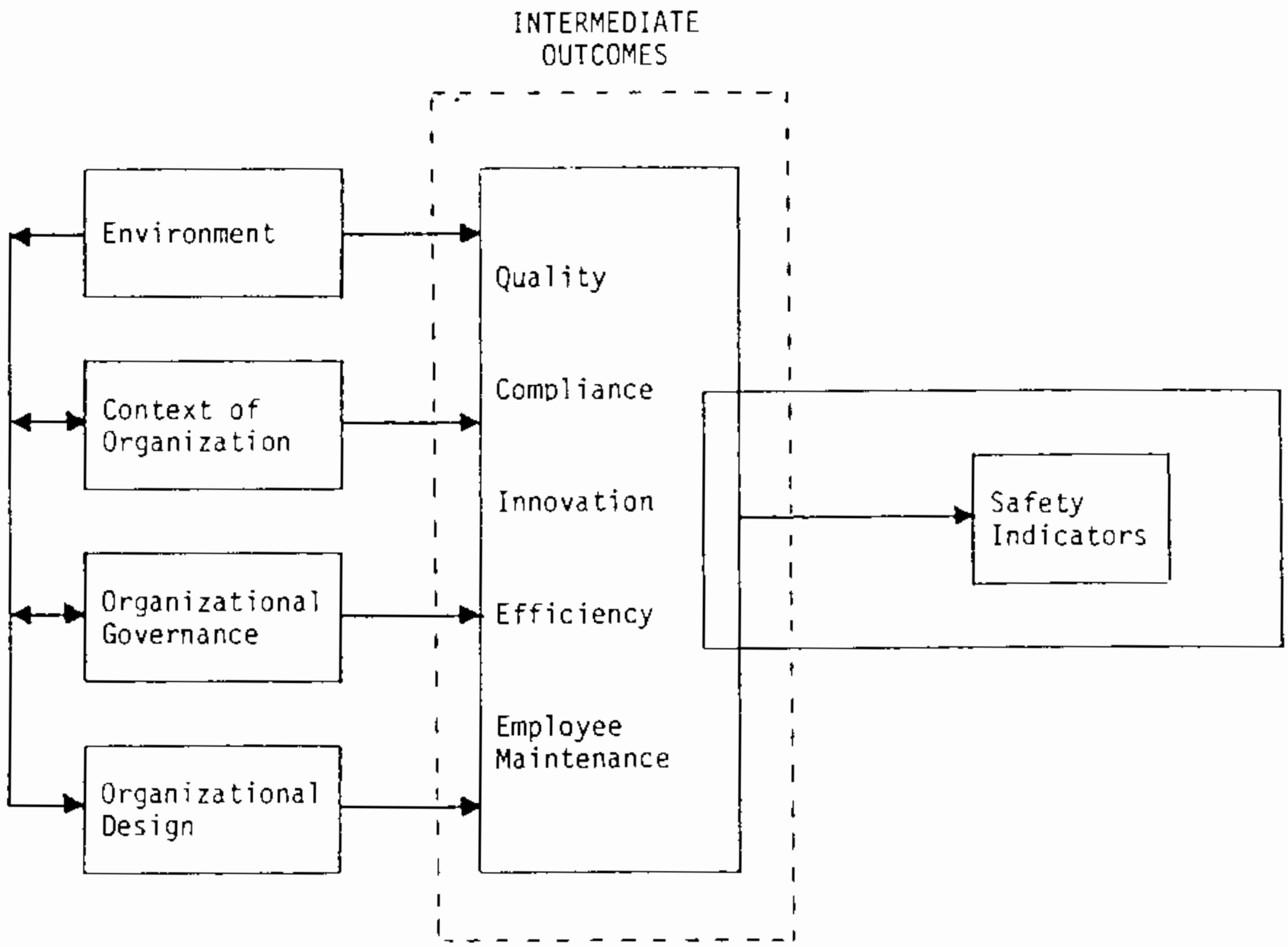

Figure 2. Descriptive Analytical Model of the Relationship of Organizational Factors to Safety Highlighting Intermediate Outcomes

4.2 Safety and Efficiency

One link between efficiency and safety appears to center on the nature of nuclear power plant technology. Nuclear power plants appear to be safest when they are operated consistently (PDRI, n.d.). Major changes in system operating parameters may suggest threats to safety through deficiencies in systems, components, or equipment. Consistency in operations can be seen in on-line performance and reflected in its efficiency rating (see Volume II, Chapter 6). Thus, the more efficient plant, over the intermediate term, is likely to be safer than one experiencing more frequent unplanned outages. For instance, wide, dramatic changes in temperature and pressure put a strain on the system, while fluctuations in operating parameters (e.g., water chemistry) can make the plant more difficult to control. Over the entire range, this relationship may not hold. It is possible to obtain high efficiency (low unplanned outages) at a sacrifice to safety. And, of course, utilities may plan extended shutdowns, as in the case of Trojan. Thus, raw efficiency ratings need to be adjusted prior to interpretation as safety indicators (see Volume II, Chapter 6). A second link is through the work process, where efficiency in the work process can be expected to lead to increased safety. Properly designed procedures provide a step-by-step pattern for those work activities which call for specific predetermined sequences. Unexpected, unplanned, and superfluous (that is, inefficient) behavior is minimized. A common finding in the safety literature is that consistency leads to better safety performance (Riggs, 1981; Heinrich et al., 1980). The logic behind this position is that consistency in procedures allows the workers to anticipate successive steps in the work process. Consequently, they are not surprised or endangered by events.

Within the nuclear industry, the efficient use of the plant is particularly relevant to safety through a third link--knowledge and control of operating conditions. Not only are nuclear power plants designed to perform most efficiently at high energy levels, but operators are trained to control the system in this mode and have the bulk of their experience with this mode.

4.3 Safety and Innovation

One key set of relationships linking structure to safety involves the mediating effects of innovation. Many productive technologies are incomplete (cf., Sutherland, 1977). That is, current knowledge is insufficient to reach the desired goals in every case. Medical technology is a case in point, and so is nuclear power production. There are many unresolved technical problems (water hammer, pressurized thermal shock, etc.) in this technology. While these problems exist, power plants may perpetuate less than acceptably safe conditions. The safety of the plants, in the long run, depends upon the solution of such technological problems. It also, however, depends upon the ability of the utility to generate and assimilate administrative innovations supportive of improved safety. For a given plant, solution to administrative and technological problems can come about either through the creation of new knowledge or from the importation of this knowledge from the environment. Both types of behavior constitute innovation.

4.4 Safety and Compliance

The link between compliance and safety is complicated by the fact that there are several forms of compliance. At the risk of some simplification, compliance can be due to external control or internal motivation (cf., Etzioni, 1975). The literature does not unambiguously state which form of compliance is best relative to safety. Though a significant fraction of the literature supports the proposition that compliance due to internal motivation is always superior, the dominant perspective at the moment is, again, a contingency perspective (Hage, 1980). This perspective would argue that where the technology is not developed to the point where clear, unambiguous rules for behavior and sanctions to enforce the behavior can be established, the organization is better off emphasizing internal motivation. Where rules and procedures can be developed, the organization might do just as well with an external control strategy. Under either perspective, however, compliance to norms of safe behavior is considered essential to the safe operation of the plant. Further, one may examine individual employee compliance or the compliance of the utility to a number of standards. Here the focus is on compliance with NRC standards.

4.5 Safety and Employee Maintenance

Finally, the literature strongly suggests that each of the other intermediate outcomes can be linked with an adequate level of employee maintenance. Employee maintenance refers to such phenomena as job satisfaction, morale, esprit de corps, retention, and the like. Organizations that do not foster these to an adequate degree are not expected to support quality, efficiency, innovation, or compliance. The literature on employee maintenance is vast and not without controversy (e.g., Osborn et al., 1980). The relationship among employee maintenance and other intermediate outcomes appears indirect. And, of course, the appropriateness of NRC regulation of attitudes must be questioned. Employee maintenance should be considered if for no other reason than utilities must keep a highly qualified work force. Regulations which negatively affect employee maintenance could degradate the long-term prospects for safe operations even though they could yield near-term improvements in efficiency or regulatory compliance.

5. SAFETY INDICATORS

This section summarizes the results of a survey and evaluation of ten existing indicators of plant safety. The ultimate goal in examining these measures of plant safety is to examine the relationships (if any) among safety indicators and the organizational characteristics of the utilities that operate nuclear power plants. Here, the immediate objective is to analyze indicators already measured by the NRC. While all of the available indicators are seriously flawed, all are not flawed in the same way. By utilizing several indicators for the same dimension of safety, it is possible to utilize multiple measurement techniques so that the weaknesses of one indicator are partially compensated by incorporating a second and/or third indicator. These additional indicators may also have weaknesses, but they are often of a different type.

5.1 Sources of Safety Indicators

The ten safety indicators evaluated and their sources are listed below. Some references are from periodic reports that do not have a single, "best source" reference and are marked "for example" on the following list.

(1) Licensee Event Reports (LERs) (USNRC, ND_c)

U.S. Nuclear Regulatory Commission, Regulatory Guide 11.6, "Reporting and Operating Information--Appendix A Technical Specifications".

(2) Inspection and Enforcement Data (766 File) (USNRC, ND_d)

U.S. Nuclear Regulatory Commission Inspection and Enforcement Manual, Chapters 0500 and 0535 (USNRC, ND_d).

(3) Monthly Operating Reports

U.S. Nuclear Regulatory Commission "Licensed Operating Reactor Status Summary Report," NUREG-0020. (Gray Book) (USNRC, ND_e).

(4) Systematic Assessment of Licensee Performance (SALP Ratings) (USNRC, ND_f)

U.S. Nuclear Regulatory Commission NRC Manual, Chapter NRC-0516, "Systematic Assessment of Licensee Performance," (ND_h)

(5) Inspection and Enforcement Staff Survey (I&E) (Cover, 1978)

Cover, S. K., 1978, "Individual site ratings from the I&E Employee Survey on Evaluation of Licensees." Unpublished manuscript.

(6) Personnel Exposure Data (e.g., USNRC, ND_g)

(E.g., U.S. Nuclear Regulatory Commission Occupational Radiation Exposure at Commercial Nuclear Power Reactors, NUREG-0713, ND_g.)

(7) Effluent Release Data

Semi-Annual Reports filed by Utilities to the NRC as required in the Environmental Technical specifications and Regulatory Guides 1.109, 1.111, and 1.113.

(8) Operator Exam Scores

File maintained by the Operator Licensing Branch, Division of Human Factors Safety, NRR, USNRC.

(9) Liability Insurance Risk Assessments

(E.g., American Nuclear Insurers, Nuclear Energy Liability Insurance Association and Mutual Atomic Energy Underwriters.)

(10) Institute of Nuclear Power Operations (INPO)

Institute of Nuclear Power Operations, "Performance Objectives and Criteria for Plant Evaluations." January 1982.

In addition to identifying available indicators for this effort, each indicator has been evaluated on the basis of the following five factors:

(1) The extent to which the indicator is reliable (e.g. repeated measurements would produce the same results).

(2) The extent to which the indicator is readily available in a form suitable for analysis.

(3) The validity of the indicator (the extent to which a specific dimension of plant safety is actually measured by the indicator).

(4) The objectivity of the indicator (the extent to which the indicator is affected by bias from differential interpretation and/or perception).

(5) The extent to which the indicator is conceptually distinct from the predictor variables. Indicators of safety that are, in fact, indicators of management and organization will lead to circular arguments and, therefore, must be avoided.

5.2 Analysis of Safety Indicators

Table 5 provides a listing of the indicators along with a summary of the conclusions regarding the indicator's standing on each of these five factors. An overall rating is also indicated. It is important to note that these evaluations concern the use of the indicator as a source of plant safety information in a statistical analysis. None of the indicators were specifically developed for that purpose. Consequently, the following evaluation says little about the indicator's ability to perform the function for which it was originally designed.

A five-point scale was used to reflect the judgments regarding each indicator's standing on the five factors. A "1" in Figure 2 means that the indicator is judged to be acceptable in its current form on the relevant factor. A "5" represents the conclusion that the indicator is unacceptable on the factor even after feasible and realistic adjustments. Values "2" through "4" represent gradients along this scale. A "2" means that the indicator is acceptable with minor modifications, a "3" means the indicator has significant weaknesses but may be adequate with adjustments, and a "4" means the indicator is only marginally acceptable with major modifications.

Chapter 6 of Volume II provides detailed descriptions of each of the indicators, a summary of previous efforts to utilize them in assessing plant performance, and the rationale underlying each of the evaluations in Table 5. The conclusion of this analysis is that the following have potential for the measurement of plant safety: Licensee Event Reports, Inspection and Enforcement Data, Monthly Operating Reports, and a potential

TABLE 5

SUMMARY OF THE EVALUATIONS OF PLANT SAFETY INDICATORS

Indicators	Reliability	Availability	Validity	Objectivity	Conceptual Distinctness	Summary Evaluation
Licensee Event Reports	2	2	3	4	3	3
Inspection & Enforcement Data	1	1	3	3	2	2
Operating & Outage Data	1	1	3	2	3	2
Systematic Assessment of Licensee Performance (SALP)	3	2	3	3	3	3
I&E Staff	3	5	3	4	2	3
Personnel Exposure Data	1	1	3	3	3	3
Effluent Release Data	2	2	2	2	2	2
Operator Exam Scores	3	3	4	3	5	5
Liability Insurance Risk Assessments	3	5	3	3	3	5
INPO Plant Evaluations	4	3	4	4	5	5

The values in Table 5 represent evaluations of the indicator on each factor and an overall summary evaluation. A "1" represents the best evaluation and a "5" represents the worst. See text for definitions.

survey of Inspection and Enforcement staff. This last indicator does not yet exist so Systematic Assessment of Licensee Performance reports (SALP) are recommended as a short term (but problematic) substitute.

Chapter 6 in Volume II also contains the rationale for omitting the other indicators listed in Figure 2. Briefly, personnel exposure and effluent release data were considered valuable indicators, but since non-trivial variations in exposures and effluent release are reported in LERs, it was not necessary to include them. Operator exam scores were rejected because they are a better indicator of the determinants of safety than safety itself. Their use as safety indicators would result in a tautological argument. Liability insurance risk assessments may have been a valuable data source, but they are regarded as proprietary.

Finally, the INPO evaluations are not included at this time for two reasons. First, the evaluations are directed at management and organization characteristics. Their use as indicators of plant safety may, therefore, be tautological. Second, from the information available at the time, it is not clear what empirical criteria are used to make the INPO evaluations. For example, the conclusion that a plant follows "good operating practice" is not useful without an operational definition of "good practice" and some evidence that "good practice," however defined, is linked to safety.

6. SELECTED PROPOSITIONS

In this section we will present some selected propositions from the literature linking our broad categories of environment, context, governance, and design to intermediate outcomes and, hence, to safety. The propositions that we present here are those that we feel to have the greatest potential for explaining variation in plant performance. Additional propositions have been framed in the relevant sections of Volume II. The propositions are labeled E for environment, C for context, G for governance, and D for design. With a focus on organizational design, we provide a more extended discussion of one major proposition.

6.1 Realism and the Focus on Organizational Design

Before stating propositions, it is important to note that a realistic view suggests that some factors are more amenable to change than others. The decision to go nuclear, for instance, brings with it a host of regulatory considerations, a new series of suppliers, and a plant with an expected lifetime of over 25 years. Aside from changes by the NRC, many, if not most, of the environmental characteristics salient to utilities are far beyond their influence and control. While there may be small alterations in size and technology, these factors may vary within a comparatively narrow range over extended time periods. In more common language, the utility must successfully operate the plant it has within the region it is located and under the regulatory framework of local, state, and federal agencies.

While the character and type of organizational governance may be more amenable to change than the environment, technology, or size, wholesale changes in the top management of utilities are comparatively rare. As we noted, utilities, as a group, are among the oldest organizations operating within the U.S. Many appear rich in tradition with stable career paths for executives and an implicit policy of internal succession. For instance, the emergence of top utility executives with extensive nuclear experience is a comparatively new phenomenon.

Nuclear utilities are protected from the most severe consequences of the market, yet they face an uncertain, highly interdependent, and contentious set of external forces. These institutions contain one of the most advanced, sophisticated, and intricate forms of technology currently being employed. While these institutions are asked to emphasize quality and innovation, there are sustained pressures for greater efficiency. Moreover, they must comply with more rigid regulatory prescriptions resulting from the Three Mile Island incident. In different terms, the ecological niche of nuclear utilities appears precarious.

One might expect that organizations with a broad range of choices would move away from such an apparently dismal situation. But the nuclear utilities cannot. The very regulations that protect them from demise also constrain their options. Thus, patterns of environmental conditions, context, organizational governance, and organizational design which would appear incongruent must persist.

If one presumes that the environment, context (size and technology), and form of organizational governance are difficult to change, then the design of the organization becomes a major mechanism for adjusting to the inconsistent pressures outlined above. To the extent that the design of the organization is not capable of reconciling these inconsistent pressures, the burden falls on individual managers and workers. Even if one presumes that utility executives and employees are unusually competent, the implication for safety is clear. Organizations with greater incongruity place too much emphasis on individual action to presume safe operation of a nuclear power plant over its operating life. Just as we do not know which atom will split in a chain reaction, we do not know which mistake, oversight, or failure may threaten public health and safety. Yet we can expect that as incongruity increases the likelihood of error increases.

6.2 Environment and Contextual Factors

In this section we will present a set of general propositions linking environment and contextual factors to safety through the intermediate outcomes. All propositions are stated under the assumption that all other factors are constant.

6.2.1 Environmental Propositions

Three factors are important to consider relative to the general and specific environment. These are the degree of abundance of resources, the amount of volatility or unplanned change, and the amount of interdependence within the environment. When these three factors are considered together, the complexity of the environment may be charted.

The degree of complexity in the environment has significant effects on the organizational design employed by organizations. There is an apparent tendency for organizations operating in rapidly changing, highly interdependent, and resource scarce environments to adopt a more organic type form (e.g., Osborn et al., 1980). The logic behind the organization's adaptive pattern is simple. Organizations that have rapidly changing, resource scarce, and interdependent environments are not in the position to develop mechanistic patterns of administration, coordination, or control. Rather, they must constantly change their modes of operation to keep up with the demands of the environment. This means a reliance on a more flexible approach to organizational design. The organic form provides this flexibility with its emphasis on free-flowing communication, decentralization, and the like. Some studies have also suggested that organizations operating in a complex environment but characterized by a mechanistic design, perform less well than organizations with designs congruent to the demands of the environment (e.g., Burns and Stalker, 1961). However, nuclear utilities also face regulatory pressure for a mechanistic pattern and feel similar pressures from their size and age. Further, due to the expected associations among utility ownership and the complexity of the environment, a more complex form of governance is likely to emerge. These considerations suggest the following propositions:

E_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 which will promote quality, innovation, compliance, efficiency, and employee maintenance.

E_2: With greater environmental complexity (sustained over a lengthy period) there will be a shift toward a federal form of governance and a more diverse organizational design.

E_3: The direct or main effect of the 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.

6.2.2 Contextual Propositions

In this section we will address some key propositions relating organizational size and two aspects of technology (sophistication and variability) to the intermediate outcomes. Here we emphasize the indirect associations. Specifically, the propositions concern the interface among contextual factors, organizational governance and organizational design.

6.2.2.1 Size

As organizations vary in size, they tend also to vary in terms of quality, innovation, compliance and efficiency. A key factor is that large organizations tend to become both more bureaucratic and more complex than their smaller counterparts. In large organizations, one expects to find increasing use of impersonal mechanisms of control on both individuals and the productive process itself. The tendency is for the larger organization to become more "rules driven," leading to a decline in the concern with quality, an overall decline in employee maintenance, and an ossification which frustrates innovative activity. However, it is also important to point out that very large organizations are in a better position to hire specialized staff than their smaller counterparts. Further, many large organizations may circumvent some dysfunctional aspects of their size by adjustments in organizational design. For example, specialized technical units may be protected and provided a more organic structure. If such units are not subjected to mechanistic organizational forms, increasing organizational size need not lead to lower levels of innovation. For the nuclear industry, we also expect to see the moderating influence of organizational governance. Thus, we offer five size propositions for the nuclear portion of the utility presuming traditional and modern forms of organizational governance.

C_1: The larger the nuclear organization, the more mechanistic it is and the less it tends to emphasize quality.

C_2: The larger the nuclear organization, the more it can take advantage of economies of scale and the greater its potential efficiency.

C_3: The larger the nuclear organization, the more mechanistic it is and the less effective the organization is in achieving employee maintenance.

C_4: The larger the nuclear organization, the more it relies on formal rules to achieve compliance.

C_5: The larger the nuclear organization, the more likely formal rules will frustrate the innovative process and the more likely specialized staff will emerge to take over the function of innovation.

For the utility as a whole, we offer the following proposition:

C_6: The dysfunctional effects of size on intermediate outcomes may be partially offset by a change toward a federal form of organizational governance and a more diverse organization design.

C_7: In huge utilities, or where large utilities operate several new nuclear facilities, a separate nuclear division will emerge.

6.2.2.2 Technology

Reactor designs vary by vendor and age. Generally, as organizations increase in technological sophistication (e.g., newer, larger plants) they tend to put more and more resources into their technology and the people whose responsibility it is to manage the technology. As a general expectation, then, increasing technological sophistication is associated with an increasing concern with issues of quality and innovation, and a decreasing ability to achieve compliance and efficiency. These same effects can be seen through the mediating effects of organizational design. As the sophistication of the technology increases, it is expected that the organization comes more and more to depend upon professionals who are capable of understanding the complexities of the technology and who can contribute to the resolution of unsolved technological problems. Organizations so dependent on this type of expertise have been found to emphasize the organic form. It is the organic form that tends, also, to promote a concern with quality and innovation at the expense of tight control and maximum efficiency. However, a large part of the nuclear technology is routine and similar to basic operations. Further, the size and history of many nuclear utilities reinforces the mechanistic design tendencies consistent with a simple routine technology. These conflicting forces suggest the following propositions:

C_7: The more sophisticated the technology, the more diverse the organizational design and the greater the emphasis on quality.

C_8: The more sophisticated the technology, the greater the emphasis on innovation.

C_9: The more sophisticated the technology, the lower the efficiency.

C_{10}: The more sophisticated the technology, the lower the compliance record.

For the nuclear industry, the number of plants and different vendors who have supplied plants to a utility appears to be an important feature. Where the nuclear facilities themselves are different, experience with older plants may or may not transfer readily to the newer, larger ones. Thus, utilities with a variety of technologies will tend to be characterized by more complex organizational designs across their facilities, if the designs are to be responsive to the diverse technologies. Further, a subtle change with the nuclear component may facilitate adjustment to variety. Namely, a shift toward a federal form of governance at the top of the nuclear component may facilitate performance, since this form of governance facilitates communication.

C_{11}: Utilities with several types of nuclear plants will experience pressure toward a more diverse organizational design.

C_{12}: For utilities with several types of nuclear plants, a small movement toward a federal form for their nuclear component will be associated with higher quality, innovation and employee maintenance.

6.2.3 Organizational Governance

We may begin with the basic assumption that the utility board of directors as well as top management is committed to the safe operation of their nuclear facilities. This commitment should be evidenced most directly in an emphasis on quality and innovation in addition to operating efficiency. Compliance to NRC regulations which appear congruent with safe operations and cost effectiveness should not be problematical. That utility executives would define issues differently than the NRC is expected, as are differences over timing. The need for utilities to balance many issues beyond the safeness of a particular facility creates further differences between industry and regulator.

We also assume that each of the forms of organizational governance would include a concern and support for safety. However, the organizational designs consistent with the different governance forms may inhibit or facilitate the implementation of the commitment to safety. Essentially, the mechanistic tendencies associated with the traditional form would favor efficiency and compliance at the possible expense of quality and innovation. In the modern form there may be an overemphasis on a strong individual manager for a particular plant or for the nuclear operations as a whole. This may yield a somewhat erratic pattern of compliance even though efficiency may be high.

It is expected that the federal form at the top management level will provide a counterweight to the more traditional and modern emphasis expected from nuclear managers. Here the organizational design for the nuclear component should be more diverse. That is, there should be more organically structured units which are directly connected to higher corporate managers. While such a pattern may not be as efficient as others, or be rated as highly by NRC, it should promote quality and innovation. When combined with earlier analysis, we can offer the following propositions.

G_1: The traditional form of governance will be associated with higher efficiency and compliance but lower quality.

G_2: The modern form of governance will be associated with erratic compliance and higher efficiency.

G_3: The federal form will be associated with higher quality and innovation and lower compliance.

G_4: The design of the organization will be associated with the form of organizational governance.

G_5: Larger utilities and those licensees who are subsidiaries are more likely to have a federal form of governance.

6.2.4 Organizational Design and Intermediate Outcomes

In this section we address the effects of organizational design on the intermediate outcomes. The most important organizational determinants of quality from the literature are (1) a relative emphasis on a craft and professional workforce, and (2) the adoption of a more organic organizational form which is consistent with the problem-solving orientation of craft and professional workers. In the first case, the literature supports the view that craft and professional workers are more likely to be concerned with exceptions to the routine (Hage, 1980; Perrow, 1967). In the second case, the literature supports the view that craft and professional workers require an organizational form that is not highly bureaucratic, but rather allows for considerable autonomy and exchange of ideas (Hall, 1968).

The exact nature of the organizational form that promotes efficiency depends in part upon the nature of the technology involved. There is support for the view that within routine technologies, efficiency is increased through the use of bureaucratic or mechanistic forms: that is, an emphasis on rules and regulation, chain-of-command, and the like (Burns and Stalker, 1961). For non-routine technologies, however, efficiency may be promoted by an organic form that allows autonomy and interaction to a greater degree (cf., Litterer, 1973). The complication for the nuclear power industry is that each plant contains both routine and non-routine technologies. The efficient organization, then, not only must apply the mechanistic approach to routine activities and the organic approach to non-routine activities, but it should also provide a buffer between these two inconsistent methods of managing the work process. Otherwise, conflict is likely to ensue (cf., Etizioni, 1975). However, early in the life cycle of the plant, after initial shakedown, the mechanistic design may be associated with efficiency simply because equipment and systems are expected to operate as designed. Later, however, the diverse design may be more appropriate. Since the bulk of the plants are comparatively new, the mechanistic design is expected to be associated with greater on-line performance.

The literature suggests that organizations that contain a large number of professionals will be the organizations that stress innovation. It further suggests that the organization should adopt a form that allows for the free flow of information both within and across organizational boundaries to allow innovation to occur. The literature strongly suggests that bureaucratic or mechanistic organizational forms frustrate the innovation process (Hage, 1980).

The link between regulatory compliance and safety is complicated by the fact that there are several forms of compliance (Etizioni, 1975). At the risk of some simplification, compliance can be due to external control or internal motivation. The literature does not unambiguously state which form of compliance is best relative to safety. Though a significant fraction of the literature supports the proposition that compliance due to internal motivation is always superior, the dominant perspective at the moment is, again, a contingency perspective (Dubin et al., 1975). This perspective would argue that where the technology is not developed to the point where clear, unambiguous rules for behavior and sanctions to enforce the behavior can be established, the organization is better off emphasizing internal motivation. Where rules and sanctions can be developed, the organization might do just as well with an external control strategy. An organic organizational form is generally viewed as more consistent with a motivational compliance strategy than is a mechanistic organizational form. Further, the more organic form appears to foster higher employee maintenance, particularly where highly educated and trained workers are expected to help provide quality and innovation (e.g., Hall, 1968; Dubin et al., 1975; Hage, 1980).

These considerations yield the following propositions:

D_1: The more organic the organizational design, the higher the quality.

D_2: The more mechanistic the organizational design, the higher the plant efficiency for plants early in their life cycle.

D_3: The more organic the design of the nuclear organization, the higher the innovation.

D_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.

D_5: The more organic the organizational design, the higher employee maintenance.

6.2.5 The Congruity Proposition

The organizational literature and existing industry practice suggests that congruity should be emphasized. In an organizational context, congruity is defined as the organization design which helps the organization meet the demands, constraints, and opportunities placed upon it by the environment, context, technology, and governance patterns. If the safety of a nuclear power plant is defined in terms of the intermediate outcomes (quality, innovation, efficiency, compliance, and employee maintenance), then a congruent organization design will permit and facilitate adequate performance on each of these intermediate outcomes, thereby contributing to safe operation of the plant.

When applied to the nuclear power industry, the congruity concept argues that the organizational design for the utility, nuclear operations, and the plant would likely be quite complex. Some aspects of plant operations appear to require routine operation using very well-established technology. Here a machine-like structure (mechanistic) appears appropriate. Other aspects of the nuclear power operations require professional and craftsmanlike skills in an environment characterized by significant uncertainty. Here, a more flexible organic structure may be necessary to achieve good performance. Where the mechanistically and organically structured portions of the plant must work together, a number of integrative mechanisms may need to be created. For instance, some utilities utilize a matrix structure to aid integration. Others use a separate series of departments for independent safety review.

It is apparent that organization design which is adjusted to a number of environmental and contextual factors beyond technology is likely to yield higher intermediate outcomes than one attuned just to technical dictates. Thus, one organizational design for each type of plant (e.g., BWR, PWR) does not appear desirable. It is expected that the organizational design for the utility and nuclear operations will reflect adjustments to environmental, contextual, and governance factors. Where such adjustments are not reflected in the organizational design for a particular plant, the congruity propositions would suggest that, over time, one should expect safety problems.

7. RECOMMENDATIONS

For the NRC, one of the most telling "lessons learned" from the Three Mile Island incident was the importance of human factors in general, and the critical nature of utility management and organizational design in particular (e.g., Crocker, 1981). While the potential importance of management has been historically recognized by the NRC, our analyses suggest that NRC can tap the growing store of scientific knowledge concerning organizational analysis.

Our recommendations are divided into two sections. The first section is concerned with general recommendations based on possible strategies emerging from the proposed NRC Human Factors Plan (USNRC, 1982). The second series of recommendations is based on extensions of the literature review with a focus on safety indicators, the environment and context of the utility, organizational governance, and organizational design.

7.1 Limitations and Assumptions

Before noting general recommendations, it is important to reiterate three apparently conflicting conditions. One, organizational analysis is comparatively new and the bulk of the extensive research is centered on improving the efficiency of larger organizations (see Osborn, Hunt, and Jauch, 1980). While the literature is often applied in character, with an increasing emphasis on empirical analysis, there are few, if any, comprehensive studies of nuclear operations which identify those organizational aspects linked to safety. If the goal of the NRC were to increase the short-term efficiency of nuclear operations, direct transfers from the literature would be easier. But since the overriding interest of NRC is public safety, transfers need to be carefully analyzed. We have noted, for instance, that organizational design changes to improve short-term operating efficiency may not yield greater innovation.

The organizational literature and industry experience suggest that varied patterns of management and organization may yield acceptable outcomes. Utilities with quite different forms of organizational design have been given operating licenses (Osborn, Sommers, and Nadel, 1982). However, there is little, if any, evidence to suggest that all patterns which have been approved (or have evolved) yield acceptable levels of safety, (e.g., Marcus, Osborn, Berk, and Duvernoy, 1982).

Three, NRC has an assessment responsibility, but its role may be limited. NRC and industry share an interest in developing organizational patterns which promote safety. While NRC's task is to ensure adequate management and organization for public safety, it is often recognized that NRC cannot manage the facilities. The organizational literature and prior NRC work suggests that assessment may be separate from day-to-day management (e.g., Ryan, 1982; Haas, 1982). A focus on organizational analysis instead of management or technical functions may help both NRC and industry to recognize their separate but complementary roles.

The recommendations outlined below are based on three basic assumptions. One, analyses can be tailored to draw upon the existing literature and provide additional bases for guidelines and regulation where the regulatory alternatives include a heavy reliance upon self-regulation. Two, improvements in existing criteria and processes for assessment can be implemented (in the near term) and still be formulated to incorporate applied research findings (Nadel, 1982; Osborn et al., 1982). Three, carefully developed and integrated strategies for analysis can promote continued improvement and refinement in the NRC and regulatory actions.

7.2 General Recommendations

The next section discusses possible strategies for improving assessment and charts the strategies emerging from NRC's human factors plan (NRC, 1982). Then we discuss how these strategies can be used to treat issues identified in the human factors plan. The issues discussed are: improving existing assessments and guidelines, the need to bolster subjective judgment, resolving Task Action Plan items, lack of objective measurement, regionalization, and development of advanced systems. The section closes with a discussion of possible pitfalls.

7.2.1 Possible Strategies

There are several pure strategies NRC may take in an effort to improve and refine its regulatory posture regarding the management and/or organization of utilities holding or seeking an operating license.

7.2.1.1 Judgment

One strategy is to rely upon judgment and experience to develop and implement guidelines (or other regulatory instruments). Here, both the determination of the areas subject to constraint and the types of constraints would follow the knowledge and experience of NRC reviewers, industry representatives, and/or management experts. Essentially, this strategy has been used by the NRC almost exclusively in assessing management and organization (e.g., NUREG 0731; Kim, 1982). And it is being employed by the Institute of Nuclear Power Operations in detailed assessments of particular plant practices (INPO, 1981). This strategy is limited and needs to be supplemented.

7.2.1.2 Direct Application of Theory

A second strategy is to base regulatory action on explicitly stated theory. Areas subject to regulatory action and the types of constraints would be based on a series of propositions and explicitly stated hypotheses. Logical consistency, face validity, and support in other settings would be used to assess the potential usefulness and veracity of propositions and hypotheses. This strategy may or may not be supplemented with analyses of regulatory impacts. In the case of the post-TMI requirement for an Independent Safety Engineering Group, explicit theory is being complemented with an analysis of how utilities implemented a new general requirement (see Marcus et al., 1982). Direct application of organizational theory is premature. The nuclear industry is unique and the theory is not sufficiently developed or tested.

7.2.1.3 Empirical Verification

A third strategy is to rest regulatory action on empirically verified relations (e.g., among environmental, contextual, governance, design conditions, and measured safety indicators). This strategy would call for longitudinal analyses of data. For instance, specific, identifiable aspects of organization design and safety would be examined over time to isolate statistically significant relationships. This strategy provides the clearest and most easily defensible long-term basis for regulatory action. The lack of empirical organizational analyses of the nuclear industry should be rectified immediately.

7.2.1.4 Burden of Proof

The first three strategies implicitly presume that industry is a passive actor which awaits regulatory action or external assessment. There is substantial anecdotal evidence to suggest that industry members believe that the administration and organizational design of nuclear operations is within their domain and that they are acting to improve their performance in these areas (Widrig et al., 1981). If it is additionally presumed that both NRC and the industry share a common interest in sound organization for long-term safety, a fourth strategy may be appropriate. Specifically, the "burden of proof" for developing sound administration and organization may be placed on applicants and those already holding an operating license. Here, NRC would develop guidelines outlining areas to be described and develop mechanisms for assessing the completeness and rationale underlying utility management and organization. Utilities would submit a plan covering key areas and be prepared to provide a rationale for key choices. Day-to-day management of the utility and plants would not be covered in the planning documents, nor is it likely NRC would be able to assess many informal characteristics. Instead, NRC could focus on underlying policies (to reflect forms of organizational governance) and organizational design. Prescriptive guidance could be held to a minimum and/or explicitly based on one of the other strategies. This strategy could be employed in areas where NRC prescriptions have yet to be formulated and/or where research directly applicable to nuclear operations is lacking. (See Osborn et al., 1982, for a more complete discussion.) Such a strategy would allow for industry initiative and flexibility, while also providing a more valid and reliable source of information.

7.2.1.5 Mixed Strategies

It is likely that a mix of these strategies will be employed. For analyses of specific functional areas, such as quality assurance, NRC may rely upon a mix of judgment and direct application of theory. For analyses of training, it may combine empirical work with judgment. And in analyses of utility organization, it may combine the burden of proof strategy with empirical analysis and judgment.

7.2.2 Using Organizational Analysis to Help Solve Identified Problems

A key question is whether or not organizational analysis can help improve existing assessments, center on objective measures, facilitate regionalization, and/or promote effective deployment of advanced systems resulting from other NRC efforts.

7.2.2.1 Improving Existing Assessments and Guidelines

The existing assessments of an applicant's organization and management are based on a loose network of individual judgments which cannot be directly supported with theory or data (see Nadel et al., 1982). Often it appears that more reliance is placed on individual managerial experience and subjective estimates of managerial competence than on organizational factors per se. Further, there also appears to be considerable emphasis on specific functional areas. Our analysis would suggest a consideration of organizational design for the utility as a whole; the nuclear component (for larger utilities) and the plant/facility.

Successful implementation of any regulatory action in this area appears to call for close linkage between the assessors and those to be assessed. Thus, NRC may need a more comprehensive understanding of the organizational aspects of nuclear utilities. A common industry-wide data base concerning current industry organization could be one starting point. It could be used for comparison across licensees and/or for analyses of proposed changes. This data base should also include the safety record of plants/facilities for comparisons and analyses, as suggested below.

7.2.2.2 The Lack of Objective Measures

While both management and organization have been identified as "root" causes for many problems within the industry, rarely can analysts point to measurable factors which can be logically linked to safety.

Unfortunately, basic information which is current, comprehensive, accurate, and interpretable is lacking. For example, organization charts in Technical

Specifications are often incomplete, based on quite different formats, contain only scattered information on offsite support, and rarely recognize the existence of other facilities. Thus, it is not possible to clearly describe comparatively simple conditions such as the existing pattern of administration. To continue the example, estimating the types of departmentation, the number of levels of management, or the number of managers for facilities is virtually impossible. The literature clearly suggests more objective measures can be developed.

7.2.2.3 Regionalization

While current NRC plans for regionalization are still being refined, it is recognized that selected portions of administration and organization assessment may be decentralized. To the extent that regions become directly involved in organizational analysis, the efforts to develop more systematic and objective assessment techniques become more even important (e.g., Nadel, 1982). It is one thing to have a select, restricted, and interactive group of individuals applying professional judgment for assessing utility management and organization. It is quite a different situation when assessments are made by scattered individuals who must perform a variety of roles. There is little compelling reason to suggest that utilities should be subject to different regulatory requirements simply because they are located in a particular NRC administrative region.

Based on an organizational analysis, NRC could develop guidelines and assessment manuals to form the basis for a common procedure across all regions. The centralized data base could be used by regional officials to check their analyses against a broader range of utility management and organization conditions.

7.2.2.4 Development of Advanced Systems

In the longer term, work in the human factors area can be expected to yield a number of advanced techniques. The safety parameter display system is but one example. NRC could systematically estimate the management and organization challenges emanating from the deployment of advanced systems prior to formulating regulations. This is important because organizational designs which have evolved over time may or may not be suitable when new information technologies are introduced. Instead of waiting for utilities to experiment (with some developing inappropriate responses), analyses could be initiated to anticipate key issues in successful implementation. Specifically, with expanded data and information capabilities, NRC and/or industry could map proposed advanced technologies onto existing organizational designs to detect gaps, inconsistencies, and overloads. The extent to which new advances call for different types of employees, for instance, may also suggest that slightly different forms of organizational design might be appropriate and/or expected. Further, the capability of utilities to successfully incorporate advanced technologies could be examined. Here, for instance, the cited research suggests that the organizational forms most conducive to successful implementation of advanced technologies may be quite different from those which elicit compliance to preset routines.

7.2.3 Pitfalls to the Successful Use of Organizational Analysis

Since organizational analysis is new to the NRC, it is important to recognize some potential pitfalls. There are a number of appealing but less fruitful approaches to organization, and it would be premature to blindly accept any one perspective (including that embodied in this report). NRC should expect some push for a direct transfer of findings from other regulatory settings and/or industries. The nuclear industry is unique in several respects and direct transfer may or may not yield regulatory action which promotes safety. For example, there are several compelling reasons to suspect that the Navy nuclear experience may only be partially transferable to commercial settings. (See Volume II, Chapter 2 for a more complete discussion).

There may be pressures to transfer analytical techniques used for investigation from technical areas. Techniques useful for analyses of technical functions deep within huge geographically dispersed organizations may not be applicable for analyses of independent organizations. For example, analytical techniques which presume that all individuals or units with the same title face the same demands, constraints, and opportunities are not likely to yield results which generalize to all nuclear utilities.

There is often the presumption that an organization is a sophisticated series of machines run by managers where each manager is charged with running a particular machine. Following this logic, the regulator can establish detailed specifications for each machine and the qualifications necessary to operate it. This analogy consistently yields analyses and regulatory actions inconsistent with the reality of organizations and their managers. For example, the addition of a "new piece of equipment" for safety review (called an ISEG, for Independent Safety Engineering Group) did not yield an independent back-up, as one might expect if redundant equipment were placed in a facility. Instead, the character of the utility's safety review system changed (see Marcus et al., 1982).

Perhaps the most important pitfall results from the combination of three interrelated misconceptions. First, each manager logically thinks s/he has an understanding of management and organization based on experience. What has worked for them will work for all managers. Organizational analysis may be equated to management, and management may be seen as an applied art where "good" management is simple and the same regardless of what or who is being managed. If any one finding characterizes modern organizational analysis, though, it is that a number of factors, including the goals to be sought, the environment of the system as well as its context, form of governance, and organizational design, should be considered jointly. Second, many managers see an analysis of management and organization in political terms, since much of their day-to-day experience involves organizational politics. From a purely political standpoint, independent organizational analyses may be seen as a potential threat to managerial prerogatives. We think it is important to distinguish management from organizational analysis, and again repeat a central theme in this report--it does not now appear appropriate for the NRC or industry itself to prescribe common organizational remedies for nuclear utilities. The third misconception is the natural tendency to equate description with evaluation and then anticipate corrective action. If one presumes there is a one best way of managing nuclear utilities, then descriptions are often equated with evaluations. It should be clear our review suggests quite the opposite.

7.3 Specific Recommendations

In this section, we outline specific recommendations for improving NRC capabilities.

7.3.1 Utility Environment and Context

The environment of a utility and contextual factors appear to have both direct and indirect associations with intermediate outcomes. Thus, we recommend the following:

(1) Available data from the Nuclear Regulatory Commission, the Department of Energy, and the Securities and Exchange Commission should be compiled into a single utility-by-utility data base and checked for consistency and reliability. A single integrated, publicly-available data base with several years of data would be an important aid to the research community and a basis for more detailed analysis. Detail on environmental and contextual factors impinging on nuclear utilities would distinguish this data base from the existing public data bases.

(2) Analysis should be undertaken to chart the relationships among environmental and contextual (size and type of technology) variables and selected utility and plant level organization design and governance factors. This analysis would aid NRC staff in interpreting the governance and design choices made by licensees and license applicants. This recommendation is obviously dependent on the availability of adequate data on organization design and governance --which is the subject of separate recommendations below.

(3) The direct relationship of environment and context variables to intermediate outcomes indicative of safety should be tested in empirical studies. It may be that some safety problems stem directly from the environment or context in which the plant operates. While mitigation of such problems would be difficult for the NRC, knowledge of such possible relationships is a first step towards meeting NRC's mandate to protect the public health and safety. The recommendation also depends on the successful completion of other recommended research efforts aimed at constructing useful intermediate outcome indicators.

7.3.2 Organizational Design

There is a great need to improve the quality of the organizational design data available to the NRC if the NRC wishes to do any of the following:

(1) Establish and maintain an accurate, up-to-date description of the organizational designs of utilities operating nuclear power plants.

(2) Engage in a systematic assessment of the relationship between organizational design characteristics and nuclear power plant safety.

(3) Monitor industry submissions and the evaluations of third parties (INPO) as to the adequacy of organizational design characteristics.

There are several tactics available to the NRC for assuring improved organizational data. The first tactic involves some minor changes in the way in which the NRC currently approaches data collection through the Final Safety Analysis Reports (FSARs). The NRC could probably generate quality organizational data at a minimum of additional effort on the part of industry by establishing a standardized format for updating FSARs. Since the utilities are required to update the FSARs anyway, providing a standardized format that reflects the dimensions of organizational design judged to be important might actually ease the burden on the industry by making clearer exactly what information is required.

A second tactic would be to take a very active role in the activities of third parties. In order to assess the quality of the data collected by such organizations as Institute of Nuclear Power Operations, the NRC should negotiate direct access to the data and should make sure that information on organizational design is routinely and systematically collected.

7.3.3 Safety Indicators

Given the charge of the NRC to protect the safety of the public, it is not surprising to find that the NRC collects a great deal of safety-related information. While the available data are substantial, they are not currently designed for the purpose of an analysis of safety such as described in this report. However, with some modification the current indicators could be greatly improved. Those changes would fall far short of solving the many problems described in Chapter 6 of Volume II, but they would move the NRC closer to having the capability of measuring plant safety and examining the extent to which it varies by plant characteristics such as organizational factors. The following are recommendations for improving the analysis potential of these indicators:

(1) Code Licensee Event Reports (LERs) for severity in terms of the potential for public risk (perhaps with a probabilistic risk assessment based calculation).

(2) Code LERs for root cause and for functional areas (i.e., operations, maintenance, health physics).

(3) Place LERs in a coded format so they could be linked by time, system, component, and cause.

(4) Conduct annual in-house surveys of Inspection and Enforcement staff to assess opinion regarding the safety of the plant and the orientation of plant staff and management.

(5) Standardize the Systematic Assessment of Licensee Performance (SALP) review process so the same methodology is used in each plant, and scores by functional area mean the same thing across plants. In addition, the time period during which the plant's performance is analyzed should be standardized.

These recommendations vary in the impact implementation might have on the NRC and the utilities. Some may be too costly or simply not possible to implement. They are provided here only to indicate that changes in these directions would do much to improve the NRC's ability to monitor plant performance and, therefore, public safety.

7.3.4 A Multiple Indicator Approach

Among the surveyed indicators, four were judged to have some potential as a contributing element in a multiple indicator approach to measuring safety. No one source was adequate alone, but the same weaknesses are not shared by all. Consequently, by combining the indicators it may be possible to capitalize on their strengths.

This conclusion suggests that the problem of measuring safety may be addressed by utilizing a long-standing tradition of measurement theory and techniques developed within the social sciences. The need to measure elusive phenomenon is common in the social sciences. In response to this need, a number of multiple measurement techniques have been built around the statistical technique of factor analysis and the more recent developments surrounding confirmatory factor analysis. Without describing the technical details of these procedures, the methodology requires that the investigator identify one or more factors underlying the associations among a set of observed indicators. These factors, or unmeasured variables, are hypothesized to cause all or part of the association among the indicators. In other words, the associations among a set of observed variables are thought to be due to the fact that they serve as indicators of the same underlying concepts or factors. These factors can be dimensions of safety or unmeasured sources of error such as self report bias. The confirmatory factor analyses approach permits the hypothesized model of factors and indicators to be statistically tested to determine if it is consistent with the data. If it is not, the model can be modified to improve the fit.

The construction of such a multiple indicator model for measuring plant safety requires access to the data sets described above. The number of indicators involved will, in part, depend on their distribution. For example, decisions regarding timeframe, division of indicators by system or cause codes, statistical adjustments, etc. all require a careful examination of the data.

It is possible, however, to illustrate the proposed technique under a number of simplifying assumptions. First, let the LER, inspection data, operating data, and an I&E staff survey serve as the four major sources of information. Second, assume, for purposes of this illustration, that these four sources are not further differentiated by time, system, cause, or any other factor. Third, assume that each indicator has been statistically adjusted for all appropriate technical factors as described in Chapter 6 of Volume II. Finally, by linking the empirical analysis of safety indicators to the conceptual foundations of the organizational literature, it is possible to suggest that quality, compliance, innovation, and efficiency are important organizational outcomes related to the safety of a facility. Again, these are intended to serve as initial hypotheses that could be confirmed or rejected only after the data are analyzed.

One model for stating the relationships among these four hypothetical factors and the indicators is portrayed in Figure 3. The four unmeasured safety related factors are illustrated by the circles. The first, compliance, particularly with NRC regulations, is a factor thought to influence variance in three of the four indicators: LERs, inspection data, and the I&E survey. This represents the hypothesis that the extent to which a plant conforms to the NRC regulations will be reflected in the number of LERs, the number of inspection findings, and the opinion of I&E staff regarding the plant.

Similarly, plant quality is hypothesized to influence variance in the LER data, and the I&E staff survey. The other two factors are seen to be reflected in the observed variance in operating data (forced shutdowns) and the I&E staff survey, respectively.

It should be noted that these hypothetical relationships between factor and indicator are subject to modification with support from the data. Furthermore, the actual analysis may suggest the need for fewer, more, or different safety factors to explain the underlying associations among the indicators.

In Figure 3, the four indicators are shown to be affected by two "bias" factors, illustrated by the two boxes labeled "Self Report Effects" and "Regulator (NRC) Effects." These two unmeasured factors are intended to serve as examples of non-safety related causes of variation in the indicators. For purposes of illustration, the self report bias is expected to account for variation in LER and operating data because they are data sets provided to the NRC by the utilities themselves. Utility practice regarding the filing of LERs and recording outage cause codes may have an effect on the variance of two indicators. Likewise, the two indicators with the NRC as the source (inspection data and the I&E staff survey) may share some association due to the fact that both involve interpretations of NRC inspectors.

Once a model such as this is defined, the next step is to estimate the parameters and assign a value to each plant on each of the underlying dimensions of safety. The solution to a measurement model such as described in Figure 3 will provide four equations (one for each factor) that can be used to assign each plant scores on safety factors. The final step is to utilize these dimensions of safety in models that incorporate environmental, contextual, governance, and design characteristics as predictors of determinants of safety.

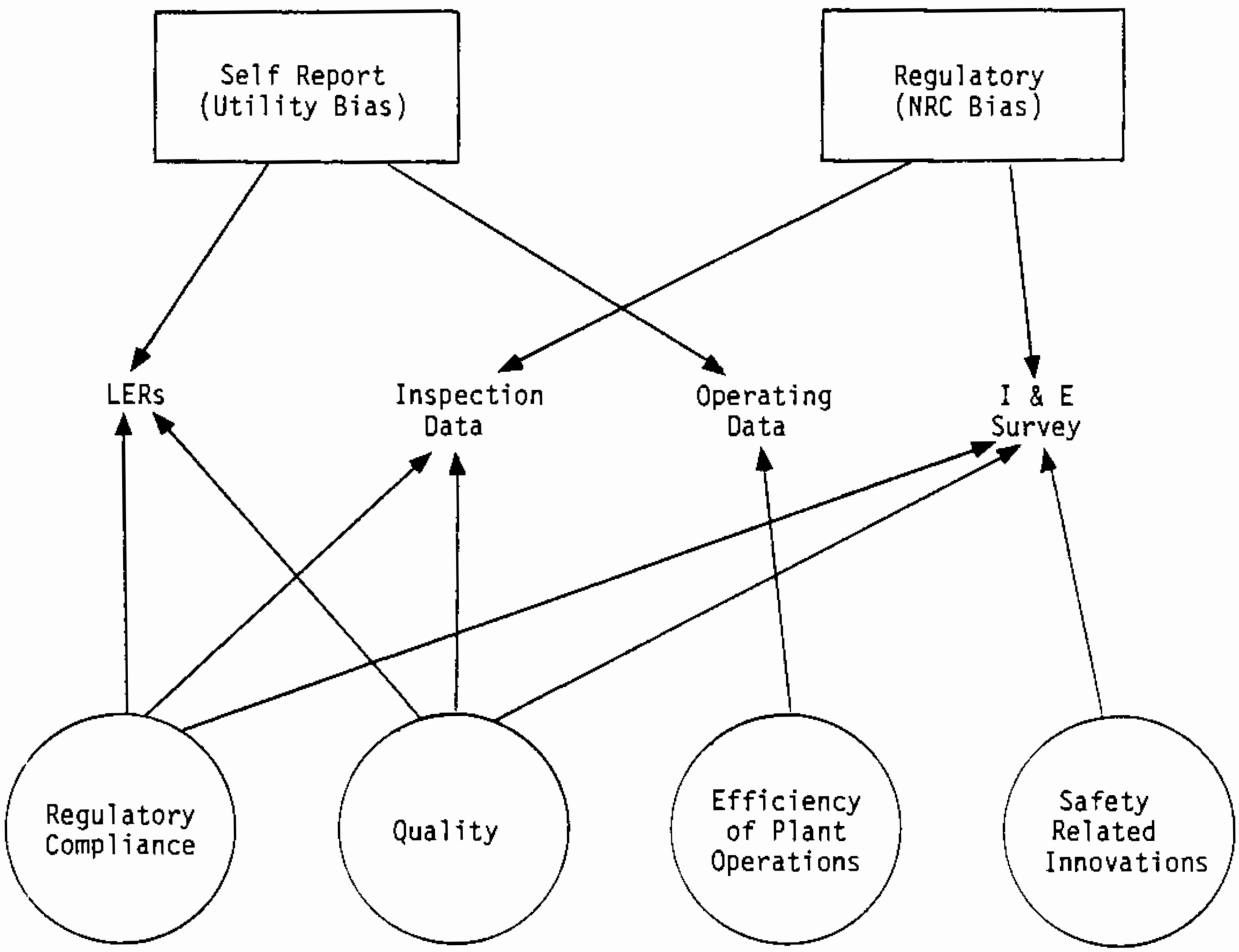

Figure 3. Hypothetical Model for Multiple Indicator Approaches to the Measurement of Plant Safety

7.3.5 Future Work

We end our list of recommendations with one most would expect. We have argued that organizational analysis can contribute to the safe operation of nuclear power plants, and that important organizational predictors can be measured. Thus, it follows that empirical investigation may substantially clarify existing associations among organizational factors and safety indicators. Controversy over the importance of organizational factors could be converted into a better understanding of the complexities of successfully and safely operating nuclear power plants. Organizational analyses can be less judgmental and attention can be focused on those variables our review suggest are potentially important for safe operations. Volume II provides more details, should this final recommendation for additional analysis be adopted.

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16. ABSTRACT (200 words or less)

Report of organizational literature focusing on potential relationships among organizational factors and safety indicators applicable in nuclear power plant safety assessments.

This report is the first of two volumes. It presents an overview of the organizational literature, and introduces a model for analyzing, singly and in combination, nuclear utility industry organizational factors (e.g., environment, history, governance, design), intermediate outcomes (e.g., quality, compliance, efficiency) and safety indicators (e.g., quality assurance, technical specifications, surveys, evaluations). Finally, recommendations are made for additional research on safety assessment approaches for assessing nuclear utility and power plant performance from organizational perspectives.

The second volume of this report presents a detailed analysis of organizational factors, intermediate outcomes and safety indicators presumed to influence nuclear power plant safety.

17. KEY WORDS AND DOCUMENT ANALYSIS	17a. DESCRIPTORS
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governance	intermediate outcomes
efficiency	safety indicators
safety	

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